

P. O. F. I. LIBRARY

JUL 22 1959

FISH & WILDLIFE SERVICE

ND

氣象庁歐文海洋報告

第10卷 第2号

THE
OCEANOGRAPHICAL MAGAZINE

Vol. 10 No. 2

CONTENTS

- S. UNOKI: Wave climate at the Ocean Weather Stations *Tango* and *Extra*... 157
- J. SUGIURA: On the sea conditions to the east off the Kurile Islands 169
- R. MARUMO, M. KITOU and M. OHWADA: Vertical distribution of plankton at 40°N, 150°E in the Oyashio water 179
- T. NAN'NITI: Relation between the velocity and the location of the front of the Kuroshio off the Tohoku district 185
- M. KITOU: Distribution of plankton copepods at the Ocean Weather Station "X", May 1950 to April 1951 193
- J. FUKUOKA: The variations of the Kuroshio current in the sea south and east of Honshu (Japan main island) 201
- M. HANZAWA: Studies on the inter-relationship between the sea and the atmosphere (part 4) 215
- M. YASUI: Internal waves in the open ocean 227



Published by the Japan Meteorological Agency

December 1958

Wave Climate at the Ocean Weather Stations Tango and Extra in the North West Pacific

By

Sanae UNOKI

Meteorological Research Institute

Abstract: The features of wave climate and the generating source of high waves at two ocean weather stations Tango (29°N , 135°E) and Extra (39°N , 153°E) are statistically investigated based upon visual observations of wave height and period, and of the scale and direction of wind waves and swell. The results are collected in several tables and figures.

1. Preface

The wave climate on open seas off Japan has scarcely been investigated for lack of systematic wave observations, although the general features of it on various coasts of Japan have been clarified to a certain degree on the basis of visual wave observations made at scores of points (Unoki, 1955). Therefore, we intend to make clear the fundamental conditions of wave at two ocean weather stations Tango and Extra in the North West Pacific arranging a great number of wave materials.

St. Tango is located at 29°N , 135°E and St. Extra at 39°N , 153°E (Fig. 1). The observations were usually carried out every three hours, and the results of them give the scale and direction of wind waves and swell, and the height and period of wave which is prevailing at each observational time, as well as usual meteorological elements. Such prevailing wave is represented by a wind wave on one occasion and by a swell on another occasion. The accuracy of the wave data is not so satisfactory because they were obtained by visual observations. In this paper we use the data in the period 1949 to 1956 at Tango and those in the period 1949 to 1953 at Extra. But the observation was sometimes interrupted on account of the sheltering of

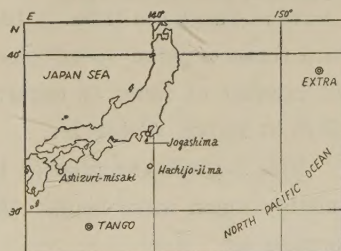


Fig. 1 Location of Ocean Weather Stations Tango and Extra.

weather ships from dangerous storms and of other inevitable circumstances. Since 1954, ocean weather ships have been engaged in observation at Tango only and during the summer and fall seasons.

2. Height, period and steepness of prevailing wave

In Fig. 2 is shown the monthly mean value of height, period and steepness of prevailing wave, and that of wind speed (Koizumi, 1956) is also added. Moreover, in Tables 1, 2 and 3 is listed the percentage of the number of times when waves with certain value of height, period and steepness occurred, respectively.

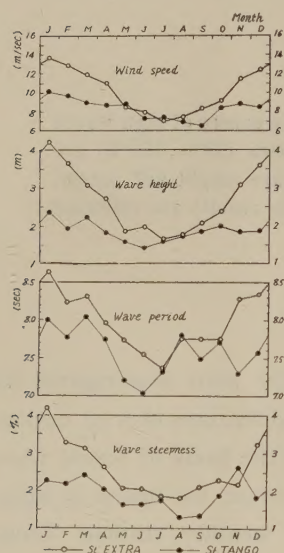


Fig. 2 Annual variation of the monthly mean value of wind speed (after Koizumi) and that of height, period and steepness of prevailing wave at Tango and Extra.

with those of wind speed (see Fig. 2). The wave height observed frequently with the number of times of occurrence more than 10% is 0.5~2.5 m at Tango and 1.0~3.0 m at Extra (Table 1).

Fig. 3 gives the relation between the monthly mean wind speed ($\bar{W}$) and the monthly mean wave height ($\bar{H}$), and we can roughly obtain such an empirical formula as

$$\bar{H} = 0.25 \bar{W},$$

where $\bar{H}$ is measured in meter and $\bar{W}$ in meter per second. The coefficient 0.25 is naturally smaller than values given by several investigators for the largest wave height produced by a given wind speed. Moreover, the monthly mean height

S. Unoki: Wave Climate at the Ocean Weather Stations Tango and Extra

Table 1. The percentage of the number of times when prevailing waves with certain heights occurred at two ocean weather stations.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	
St. Tango	(m)													
	0.0	—	—	—	0.1	—	0.1	0.3	0.9	0.4	—	—	0.2	
	0.5	4.8	2.1	1.1	7.8	15.6	21.2	22.2	18.5	22.4	5.4	9.9	14.5	12.1
	1.0	14.7	23.9	10.6	23.2	25.7	28.6	23.7	27.7	25.6	20.5	28.8	22.6	23.0
	1.5	14.0	26.6	20.4	23.5	20.7	22.1	18.9	16.0	16.2	24.0	18.4	15.7	19.7
	2.0	14.2	13.9	22.7	19.6	14.2	13.8	12.9	11.8	9.8	21.0	16.3	13.3	15.3
	2.5	16.0	15.7	18.3	7.6	13.7	6.3	10.7	7.3	7.6	12.0	7.4	12.5	11.3
	3.0	11.8	9.4	15.5	9.4	6.5	4.2	4.8	5.8	4.2	6.7	8.3	8.4	7.9
	3.5	7.2	3.5	4.7	3.0	2.4	2.7	1.7	2.8	2.2	3.9	3.4	4.5	3.5
	4.0	11.6	2.5	3.5	4.4	1.2	0.8	1.5	4.0	2.6	2.3	3.3	4.1	3.5
	4.5	3.6	—	1.9	0.7	—	0.1	1.0	1.9	1.3	1.0	1.4	1.7	1.2
	5.0	1.3	1.2	0.5	0.4	—	0.1	0.7	1.9	0.9	0.7	1.6	2.3	1.0
	5.5	0.4	0.3	—	0.3	—	—	0.2	0.3	1.0	0.3	0.3	0.3	0.3
	6.0	0.4	0.6	0.3	—	—	—	0.3	0.6	1.7	0.7	0.4	0.1	0.4
	6.5	—	0.3	—	—	—	—	0.5	0.2	0.3	0.2	—	—	0.1
	7.0	—	—	0.1	—	—	—	0.1	0.2	2.0	0.4	0.1	—	0.2
	7.5	—	—	0.3	—	—	—	0.1	—	0.4	0.2	—	—	0.1
	8.0	—	—	0.1	—	—	—	0.3	0.1	0.5	0.1	0.2	—	0.1
	8.5	—	—	—	—	—	—	—	—	0.2	0.1	—	—	0.0
	9.0	—	—	—	—	—	—	0.1	—	0.4	0.1	—	—	0.1
	9.5	—	—	—	—	—	—	—	—	0.1	0.1	0.2	—	0.0
	≥10.0	—	—	—	—	—	—	—	—	0.2	0.3	—	—	0.0
	Mean height (m)	2.4	1.9	2.2	1.8	1.6	1.4	1.6	1.7	1.9	2.0	1.8	1.9	1.9
St. Extra	(m)													
	0.0	—	—	—	—	—	0.1	—	0.2	—	—	—	—	0.0
	0.5	0.2	—	0.8	3.0	11.5	7.1	13.0	8.6	5.3	4.6	2.6	0.4	4.8
	1.0	2.1	2.8	11.7	6.6	20.7	24.1	25.3	24.6	17.7	9.7	8.5	1.1	12.9
	1.5	6.2	4.4	8.9	16.6	21.8	19.6	21.6	20.3	27.1	22.8	8.8	7.2	15.4
	2.0	10.9	13.3	12.1	20.6	15.2	19.7	18.9	16.8	16.2	20.0	12.5	12.8	15.7
	2.5	10.4	15.1	12.5	15.2	11.5	11.6	11.2	18.0	10.0	12.9	13.4	15.4	13.1
	3.0	11.5	11.8	16.1	10.6	7.3	5.8	5.7	4.8	9.0	11.6	14.7	15.7	10.4
	3.5	10.6	11.2	9.5	7.3	4.7	3.2	1.2	3.7	4.0	5.3	8.2	10.9	6.7
	4.0	12.7	14.6	8.8	6.6	4.2	4.1	1.1	1.9	5.3	3.9	9.6	11.0	7.0
	4.5	6.3	8.3	6.2	4.3	2.0	0.9	1.1	0.9	2.7	3.7	7.5	5.3	4.1
	5.0	6.0	4.3	4.3	3.5	0.8	1.6	0.8	0.2	1.2	3.0	7.8	5.3	3.2
	5.5	2.8	2.9	1.1	1.2	0.2	0.2	0.1	—	0.7	0.3	2.1	2.2	1.2
	6.0	4.0	2.4	2.8	1.6	0.1	0.7	—	—	0.2	1.0	2.5	5.5	1.7
	6.5	2.5	3.1	1.3	0.6	—	0.2	—	—	0.1	—	0.9	1.1	0.8
	7.0	3.1	1.5	1.9	0.4	—	0.7	—	—	0.3	0.3	0.5	2.4	0.9
	7.5	0.7	0.7	0.1	0.1	—	0.2	—	—	0.1	—	0.1	0.5	0.2
	8.0	2.9	1.2	1.5	1.1	—	0.2	—	—	0.1	0.2	0.1	0.9	0.7
	8.5	0.8	0.6	0.2	0.4	—	—	—	—	—	—	0.2	0.4	0.2
	9.0	1.5	0.7	0.1	0.2	—	—	—	—	—	0.2	—	0.1	0.2
	9.5	1.0	0.1	0.1	—	—	—	—	—	—	—	—	0.5	0.2
	≥10.0	3.8	1.0	—	0.1	—	—	—	—	—	0.5	—	1.3	0.6
	Mean height (m)	4.2	3.7	3.1	2.7	1.9	2.0	1.7	1.8	2.1	2.4	3.1	3.6	2.7

calculated by this formula is apt to be overestimated a little at a monthly mean wind speed less than 10 m/s, and to be rather underestimated at a monthly mean wind speed more than 10 m/s.

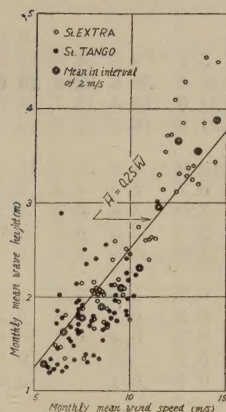


Fig. 3 Relation between the monthly mean wind speed and the monthly mean wave height at Tango and Extra.

Wave period. The monthly mean value of wave period changes almost parallel to that of wave height or wind velocity, showing that the maximum appears in winter and the minimum in summer. It is interesting that such type of annual variation agrees with a type observed on the Japan Sea coasts but differs from an observed one on the Pacific coasts of Japan where the maximum appears in fall

Table 2. The percentage of the number of times when prevailing waves with certain periods occurred at two ocean weather stations.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
St. Tango	(sec)												
	≤4.0	—	—	—	0.9	0.5	0.1	0.0	0.5	—	—	0.1	0.2
	4.5	—	0.3	—	—	1.1	0.2	0.4	0.6	—	—	0.1	0.2
	5.0	0.1	0.8	—	0.7	1.1	1.1	2.3	1.8	2.0	0.2	0.3	0.9
	5.5	—	0.5	—	0.3	1.9	2.8	1.3	2.1	4.2	1.1	0.3	0.9
	6.0	2.3	3.8	1.9	2.0	7.4	12.6	15.8	7.1	11.2	3.6	8.9	10.3
	6.5	3.1	5.9	1.5	8.2	12.8	9.4	11.4	7.8	10.6	4.8	16.8	9.0
	7.0	16.9	23.1	11.4	18.6	28.3	31.7	19.4	18.2	21.8	28.3	28.1	13.2
	7.5	7.9	16.8	11.4	11.0	20.3	13.7	12.7	13.0	9.6	17.9	14.9	7.4
	8.0	29.7	24.4	38.6	31.4	22.1	24.5	21.2	20.1	16.9	19.5	17.8	40.1
	8.5	23.0	9.2	15.3	21.1	3.4	1.9	6.1	8.3	6.1	11.0	6.3	10.1
	9.0	14.9	6.7	19.5	5.7	0.9	0.5	5.3	7.0	5.4	7.1	5.1	5.4
	9.5	2.0	2.6	0.3	1.0	0.1	0.0	1.7	4.7	1.2	1.5	0.2	0.3
	10.0	0.1	3.3	0.1	—	0.5	0.1	1.6	4.9	3.6	2.6	0.6	2.0
	10.5	—	0.3	—	—	0.3	0.1	0.0	0.5	1.6	1.0	0.7	0.3
	11.0	—	2.0	—	—	—	—	0.3	1.8	1.4	0.9	—	—
	≥11.5	—	0.3	—	—	—	—	0.6	2.3	3.3	0.5	—	—
	Mean period (sec)	8.0	7.8	8.1	7.7	7.2	7.0	7.3	7.8	7.5	7.7	7.3	7.6

S. Unoki: Wave Climate at the Ocean Weather Stations Tango and Extra

Table 2. Continued.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
St. Extra	(sec)												
	≤4.0	—	—	—	—	—	0.1	0.3	—	0.4	0.1	—	0.1
	4.5	—	—	—	—	—	0.1	0.3	0.5	0.3	0.2	—	0.1
	5.0	0.3	0.1	—	0.1	0.2	0.3	0.4	1.0	0.9	0.7	—	0.1
	5.5	0.1	—	—	1.0	0.2	1.1	2.3	2.1	1.1	0.6	0.2	0.7
	6.0	0.5	0.2	0.7	3.6	4.7	7.9	9.6	7.4	4.1	3.9	2.8	3.9
	6.5	1.5	3.2	1.1	4.9	4.7	8.2	8.5	3.3	5.0	6.2	2.2	4.3
	7.0	9.5	12.3	11.3	14.2	17.9	19.0	27.1	17.9	13.3	14.4	11.3	9.5
	7.5	8.7	8.1	10.0	11.7	14.9	13.3	17.0	13.7	17.0	18.8	9.7	11.0
	8.0	30.6	30.4	29.7	31.8	39.3	30.6	19.2	30.2	37.7	28.8	28.8	33.5
	8.5	12.8	18.0	21.2	17.6	9.5	12.6	6.4	12.4	7.2	15.3	13.8	13.3
	9.0	11.9	19.6	14.5	7.8	6.1	4.6	6.4	3.2	8.1	8.4	18.3	17.9
	9.5	6.3	4.1	4.4	2.2	0.6	0.9	1.1	0.3	2.1	1.0	2.4	2.4
	10.0	6.5	2.7	4.2	2.0	1.2	1.0	0.8	1.7	1.4	1.1	6.2	3.6
	10.5	3.0	0.2	0.8	0.3	0.1	0.2	0.3	0.1	0.9	0.2	1.9	0.6
	11.0	1.1	1.0	1.2	2.0	0.2	—	0.2	1.1	0.4	9.3	1.5	0.9
	≥11.5	7.2	0.1	0.9	0.8	0.4	0.1	0.1	5.1	0.1	—	0.9	2.2
	Mean period (sec)	8.6	8.2	8.3	8.0	7.7	7.6	7.4	7.8	7.8	7.8	8.3	8.0

and the minimum in May on account of geographical circumstances. The annual mean is 7.6 sec at Tango and 8.0 sec at Extra, and they are considerably smaller than the observed one on the Pacific coasts of Japan, for example, it is 9.2 sec at Hachijo-jima, 9.0 sec at Joga-shima and 9.3 sec at Ashizuri-misaki according to the previous paper of the author. This difference is hartly attributed to the fact that the latters were obtained in a shallow water where short waves are likely to vanish and to be merged into longer waves. The period which frequently appears is 7~9 sec at both ocean weather stations (Table 2).

Wave steepness. The measurement of wave length was not made. Therefore, we calculated the wave steepness (the ratio of the wave height to the wave length)

Table 3. The percentage of the number of times when prevailing waves with certain steepness occurred at two ocean weather stations.

Steepness (%)		0~	0.5~	1.0~	1.5~	2.0~	2.5~	3.0~	3.5~	4.0~	4.5~
Times of occurrence (%)	Tango	2.5	14.7	22.3	19.3	17.3	9.5	7.3	3.6	0.9	0.5
	Extra	0.4	6.9	12.9	16.9	18.1	14.1	9.9	5.6	5.9	2.4
Steepness (%)		5.0~	5.5~	6.0~	6.5~	7.0~	7.5~	8.0~	8.5~	9.0~	9.5~ 10.0
Times of occurrence (%)	Tango	1.0	0.2	0.2	0.2	0.2	0.0	0.2	0.2	0.1	0.0
	Extra	2.9	1.1	0.8	0.4	0.5	0.1	0.4	0.3	0.1	0.2

after the length was computed by the theoretical formula $L = gT^2/2\pi$, where T is the period. In this item the data in 1952 only were used. In general the change with month is more abrupt in the case of wave height than in the case of wave period. Consequently, the annual variation of wave steepness follows that of wave height. At Extra the wave is steepest in winter and most gentle in summer, while at Tango the maximum appears in November since the wave height was large and wave period was small in this month of 1952. The steepness observed most frequently is 1.25% (about 1/80) at Tango and 2.25% (about 1/45) at Extra, corresponding to that the swell prevails at the former station and the wind wave does at the latter station on the whole. The largest steepness was 1/10 at each station.

3. *Wind waves and swell*

The scale of wind waves and swell used in observation is as follows.

Scale number	0	1	2	3	4	5	6	7	8	9
Wind waves (height, m)	0	0~0.5	0.5~1	1~2	2~3	3~4	4~6	6~9	9~14	14~
Swell (height, m)	0	0~2	0~2	2~4	2~4	2~4	4~	4~	4~	confused
(length, m)	—	0~200	200~	0~100	100~200	200~	0~100	100~200	200~	

Tables 4 and 5 show the percentage of the frequency when wind waves and swell with certain class appeared, respectively. Annual variation of wind waves and swell agrees with that of wave height and period as a matter of course. It

Table 4. The percentage of the number of times when wind waves with certain scale occurred at two ocean weather stations.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year		
St. Tango	Scale number	0	0.4	0.3	1.4	0.1	0.6	1.7	0.9	1.9	2.1	0.4	—	2.2	1.0
		1	7.4	8.5	16.9	12.1	13.8	19.9	22.3	28.2	23.3	11.0	8.2	15.4	15.6
		2	22.3	30.1	21.0	27.3	24.8	24.8	26.3	28.4	26.3	27.1	30.0	22.9	25.9
		3	39.5	39.2	38.7	45.0	37.3	33.0	32.5	27.0	26.6	38.6	34.3	35.7	—
		4	23.1	16.2	18.8	12.9	19.7	15.9	13.5	9.2	9.2	14.1	16.2	16.6	15.5
		5	6.3	4.6	2.7	1.7	3.1	4.5	2.5	4.1	5.0	4.9	5.1	6.0	4.2
		6	0.3	1.1	0.1	0.9	0.7	0.1	1.6	1.1	2.6	3.1	2.6	2.6	1.4
		7	0.7	—	0.4	—	—	0.1	0.4	—	4.0	0.8	1.1	—	0.6
		8	—	—	—	—	—	—	—	0.1	0.9	—	—	—	0.1
	9	—	—	—	—	—	—	—	—	—	—	—	—	—	
Mean height (m)*	1.7	1.5	1.4	1.3	1.4	1.3	1.3	1.1	1.6	1.6	1.6	1.5	1.4		

S. Unoki: Wave Climate at the Ocean Weather Stations Tango and Extra

Table 4. Continued.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
St. Extra	0	—	—	0.3	0.1	0.3	—	1.3	0.5	0.4	0.6	—	0.3
	1	3.3	3.6	5.2	4.4	10.0	13.3	11.7	12.7	12.3	11.5	5.4	8.0
	2	5.5	9.3	10.8	18.2	25.0	40.2	28.1	24.5	25.4	19.5	12.5	19.3
	3	19.2	22.2	23.5	30.0	37.2	31.5	37.2	36.4	39.9	36.5	27.6	31.4
	4	21.3	22.7	25.4	26.4	18.4	7.9	18.7	18.1	14.6	19.2	27.9	20.2
	5	17.8	23.4	14.8	11.5	6.6	5.5	2.5	5.4	3.9	7.8	14.8	10.7
	6	17.4	14.0	11.1	5.8	2.4	1.0	0.5	1.9	1.8	2.0	8.9	6.7
	7	12.7	3.9	7.8	2.6	0.1	0.6	—	0.4	1.7	2.8	1.6	3.1
	8	2.8	0.9	1.1	1.0	—	—	—	0.1	—	0.1	0.7	0.6
	9	—	—	—	—	—	—	—	—	—	—	0.6	0.1
Mean height (m)*													
	3.6	2.9	2.9	2.3	1.6	1.3	1.4	1.5	1.5	1.8	2.4	2.7	2.2

* roughly estimated on the assumption that the wind wave has the central value of height corresponding to its scale number.

Table 5. The percentage of the number of times when swell with certain scales occurred at two ocean weather station.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
St. Tango	0	—	—	0.1	—	—	—	—	—	—	—	—	0.0
	1	46.5	64.0	52.1	72.6	77.0	79.6	70.4	72.4	66.3	63.6	78.9	67.5
	2	—	3.4	0.3	0.1	0.1	1.1	1.6	2.0	1.0	0.7	0.2	0.4
	3	14.9	12.0	21.1	8.8	16.0	15.2	17.5	6.0	10.9	17.3	13.9	15.3
	4	32.0	14.9	23.3	17.6	6.3	3.8	7.0	12.8	10.6	14.3	4.0	12.0
	5	—	2.0	—	—	—	—	0.2	2.2	0.9	0.6	—	0.5
	6	0.5	—	—	0.1	—	0.2	0.5	0.1	1.5	0.8	1.9	1.5
	7	6.1	3.7	3.1	0.8	0.6	0.1	2.3	3.8	6.5	2.4	1.1	3.3
	8	—	—	—	—	—	—	0.5	0.7	2.3	0.3	—	0.3
	9	—	—	—	—	—	—	—	—	—	—	—	—
St. Extra	0	—	—	—	—	—	—	—	—	—	—	—	—
	1	15.7	19.9	28.3	42.6	70.5	71.4	69.4	60.8	66.0	51.0	28.1	45.6
	2	1.0	—	1.2	0.9	0.1	0.4	0.1	3.2	0.9	0.4	0.3	0.8
	3	20.9	24.8	14.5	15.9	19.8	7.3	14.5	17.8	15.9	11.4	19.9	24.8
	4	24.0	29.4	34.3	25.3	5.8	18.1	12.3	16.4	14.9	25.7	29.4	33.6
	5	0.3	0.2	0.4	—	—	—	0.1	1.0	—	—	0.7	—
	6	2.1	3.8	4.9	2.9	1.5	1.0	0.1	0.5	—	1.5	4.0	1.9
	7	33.2	21.9	16.1	11.8	2.3	1.8	3.5	0.3	2.3	10.0	17.5	13.1
	8	2.8	—	0.3	0.6	—	—	—	—	—	—	0.1	1.7
	9	—	—	—	—	—	—	—	—	—	—	0.8	0.1

is noticeable that particularly developed wind waves and swell appear in early fall at Tango on account of frequent occurrences of severe typhoons, while at Extra they do in winter on account of prevailing northerly monsoons usually accompanied with strong extratropical cyclones.

Wave roses showing the frequency of wave direction by 16 points of the compass in per cent are rendered in Fig. 4. In almost all cases, the direction of wind

waves agreed with that of wind itself. Accordingly, we used the wind rose given by Koizumi (1956) in place of the rose of wind wave. In individual cases the

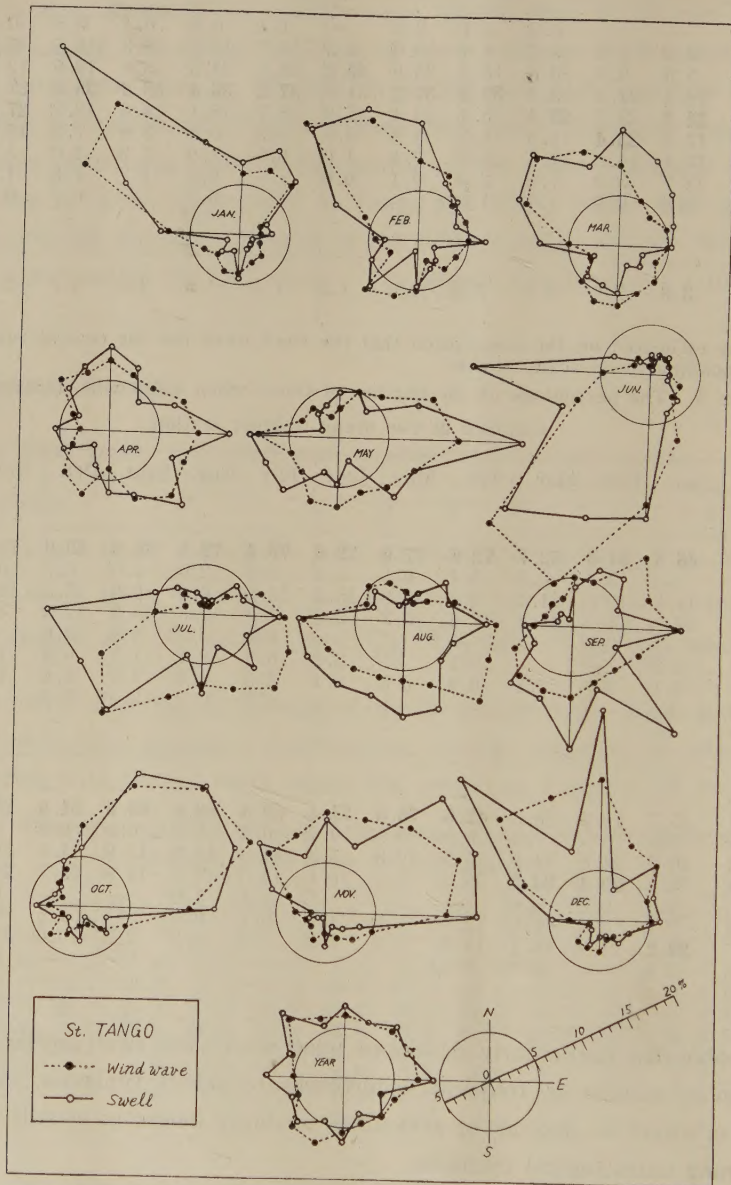


Fig. 4a Wave roses at Tango, showing the frequency of direction in percent of wind waves and swell by 16 points of the compass.

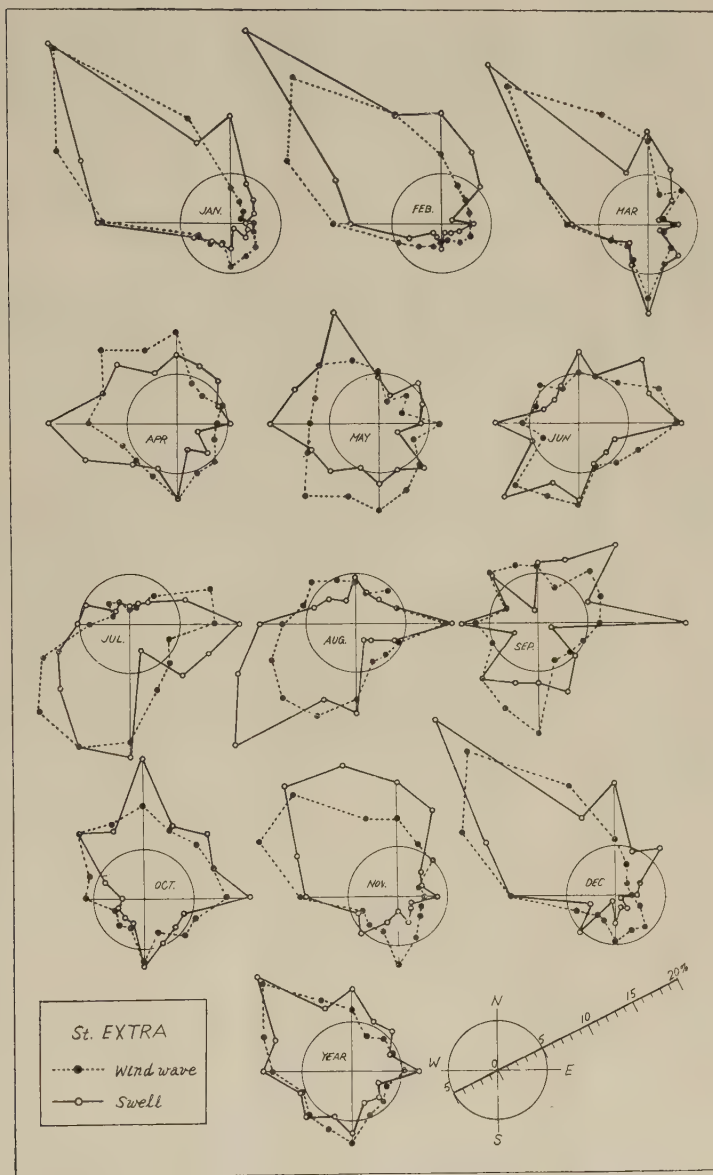


Fig. 4b Wave roses at Extra, showing the frequency of direction in percent of wind waves and swell by 16 points of the compass.

direction of swell generally differs from that of wind waves, but, so far as we consider the number of occurrence in a month, the direction of both waves fairly

accords with each other.

At two stations, the northerly wave remarkably prevails in winter and the southerly wave in summer corresponding to the direction of predominant monsoon in respective seasons. In intermediate seasons between them the shape of wave roses is complicated.

4. Meteorological conditions which cause high waves

Fig. 5 gives the number of storms which caused high waves more than 5 m during full three years. And we roughly classified these storms into three types such as a typhoon, a cyclone and a northerly monsoon in a cold season, and the result is indicated in Table 6. Notable points are as follows:

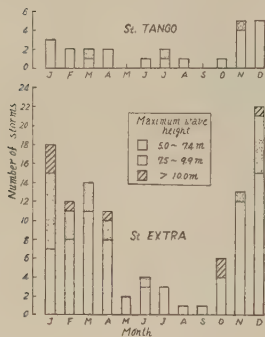


Fig. 5 Number of storms which caused high waves more than 5m during full three years from Nov. 1950 to Oct. 1953.

At both ocean weather stations the number of storms which cause high waves is more in winter and less in late spring and early fall. The total of these storms is remarkably greater at Extra than at Tango.

High waves in winter are due to severe extratropical cyclones and northerly monsoons, and those in spring and fall are due to cyclones. Agitated seas are sometimes raised by typhoons from summer to fall at Tango and in late fall at Extra, and the number of them is greater at the former station than at the latter contrary to the case of cyclones. We must note, however,

Table 6. The number and type of storms which caused high waves more than 5 meter during full three years from Nov. 1950 to Oct. 1953.

Month		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Tango	Cyclone	2	1	2	2	—	1	—	—	—	—	1	3	12
	Monsoon	1	1	—	—	—	—	—	—	—	—	2	2	6
	Typhoon	—	—	—	—	—	—	2	1	—	1	2	—	6
	Total	3	2	2	2	0	1	2	1	0	1	5	5	24
Extra	Cyclone	11	10	14	11	2	4	3	1	1	3	11	12	83
	Monsoon	7	2	—	—	—	—	—	—	—	—	1	9	19
	Typhoon	—	—	—	—	—	—	—	—	—	3	1	1	5
	Total	18	12	14	11	2	4	3	1	1	6	13	22	107

that the actual number of typhoons in question is greater than the number shown in Table 6 because it is not seldom that the weather ship leaves the designated place in order to take refuge from a violent typhoon or to pursue it.

A storm which gives rise to enormous waves over 10 m is a few, and it corresponds to a typhoon at Tango and to a winter cyclone at Extra. The greatest wave at Tango observed in the period 1949 to 1956 is 12.0 m in height and 10.5 sec in period due to Typhoon Patricia of Oct. 27, 1949, but we can expect that waves higher than 12 m would be arisen there though they were not observed on account of the refuge of the weather ship from a typhoon. The greatest wave at Extra observed in the period 1949 to 1953 is 13.0 m due to remarkably developed cyclones of Feb. 15, 1951 and Jan. 15, 1952.

Acknowledgements

The author wishes to express his thanks to the members of the Maritime-Meteorological Section, Japan Meteorological Agency, who have given him every facility for the collection of wave materials. Equal thanks are due to Dr. M. Nakano and Dr. H. Futi for their kind encouragement.

References

- KOIZUMI, M., 1956: Researches on the Variations of Oceanographic Conditions in the Region of the Ocean Weather Station "Extra" in the North Pacific Ocean (II). Pap. Meteor. Geophys. **6** (3-4), pp. 261-272.
- UNOKI, S., 1955: General Aspect of Wind Waves and Swell in the Vicinity of Japan. Pap. Meteor. Geophys. **6** (2), pp. 172-184.

On the Sea Conditions to the East off the Kurile Islands

By

J. SUGIURA

Hakodate Marine Observatory

1. Introduction

In a previous paper the author reported on the Oyashio Current off Hokkaidō. This current is derived from the sea to the east off the Kurile Islands, for this reason research of the conditions in the sea area is important for understanding of the character of the Oyashio Current. Since the war, this sea area has been under investigation mainly in connection with fisheries since 1952. But the sea area was investigated more minutely in prewar days. Especially the data obtained by the following research ships are important: the "Komahashi" and the "Itsukushima" of the Navy Hydrographic Division and the "Sōyō-maru" of the Fisheries Experimental Station. It may be valuable to study these former data on the basis of recent advanced knowledges.

The purpose of this paper is to present a detailed current pattern and to discuss the distribution of the North Pacific Subarctic Water in the sea to the east off the Kurile Islands and the Kamchatka Peninsula on the basis of the data obtained by the ships above mentioned in the period from 1933 to 1936.

2. Sea conditions to the east off the southern Kurile Islands

Two kinds of charts are presented to show the conditions in the sea area lat. 42-49°N and long. 145-160°E in regard to four periods shown in Table 1. Fig. 1 is a chart of temperatures in the 100m layer and Fig. 2 is the dynamic topographical chart relative to the 800 d.b. surface. The former chart shows approximately the minimum temperature of the inter-cooled water (dichothermal water). In the Oyashio region to the south off Hokkaidō the minimum temperature is less than 2.0°C throughout the year. Therefore the isotherm of 2.0°C in Fig. 1 may correspond to a boundary of core water of the North Pacific Subarctic Water.

Table 1. Data used in figs 1 and 2

Period	Ship	Station number	Figure
July 23 to August 4, 1933	Komahashi	L - "Yō"	Fig. 1-1, 2-1
July 26 to August 11, 1935	Komahashi Sōyō-maru	49-51, 66, 67 27-45	Fig. 1-2, 2-2
May 10 to June 3, 1936	Komahashi	1, 6, 12-19	Fig. 1-3, 2-3
July 26* to August 17, 1936	Komahashi Sōyō-maru	59-61, 78-15 ₂ 27-45	Fig. 1-4, 2-4

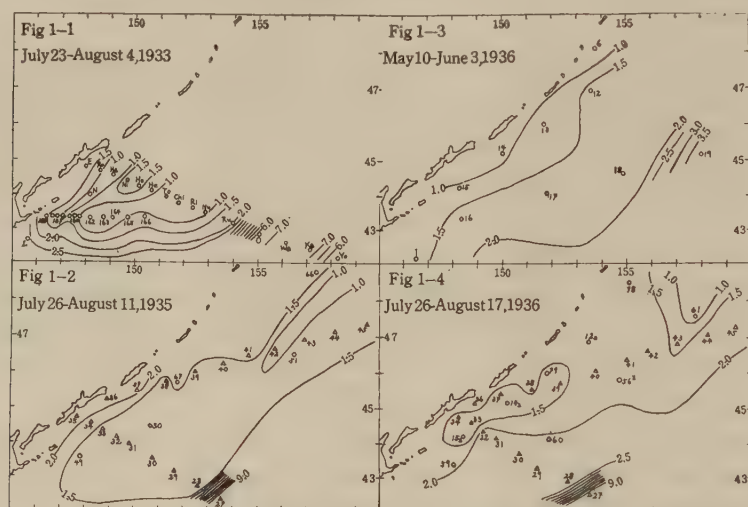


Fig. 1. Charts of temperatures in the 100m layer in the sea to the east off the southern Kurile Islands.

Circles are "Komahashi" 's stations, triangles are "Sōyō-maru" 's stations, and small numerals indicate the number of stations.

As shown in Fig. 1, the isotherm of 2.0°C in the 100m layer passes the vicinity of lat. 44°N and long. 154°E , and low temperature below 0.8°C is shown along two zones: the one located near the Kurile Islands and the other extending from lat. 47.5°N long. 158°E to lat. 43.5°N long. 152.5°E . The former zone may correspond to a cold water current flowing from the Okhotsk Sea through the straits between the Kurile Islands; the latter zone may correspond to another cold water flowing from the northern sea to the southeast off the Kamchatka Peninsula.

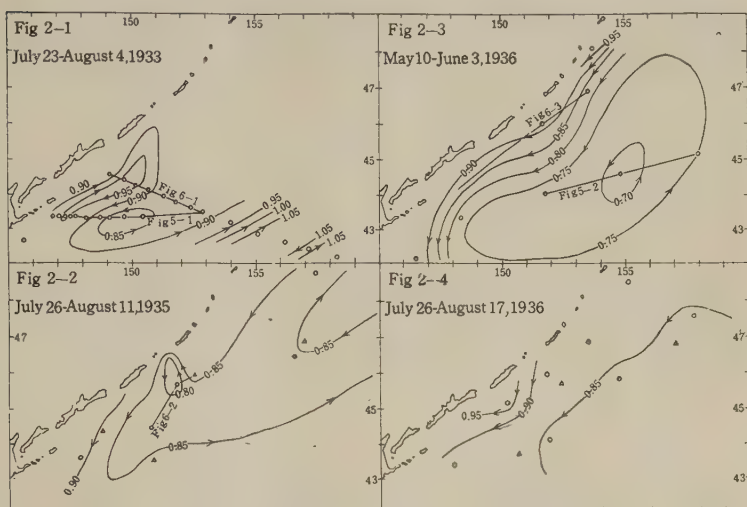


Fig. 2. Dynamic topographical charts relative to the 800 d.b. surface in the same sea with Fig. 1.

Straight lines indicate the sections shown in figs. 5 and 6.

As shown in Fig. 2, a southwestward moving current is flowing along the Kurile Islands from the vicinity of lat. 47°N , long. 154.5°E to the vicinity of lat. 44°N , long. 149°E . The Oyashio Main Current to the south off Hokkaidō (Sugiura 1957) may be an extension of this southwestward current. On the other hand a northeastward current corresponding to the Oyashio Counter Current south off Hokkaidō (Sugiura 1957) is flowing to the southeast of the southwestward moving current. Further a southward current is observed to the south of the Urupp Straits (46.5°N , 151°E) in summer (figs. 2-2 and 2-4) but not observed in spring (fig. 2-3).

3. *Sea conditions to the east off the northern Kurile Islands and the Kamchatka Peninsula*

Figs. 3 and 4 show the conditions in the sea area lat. 48-55°N and long. 153-168°E in regard to the four periods in table 2.

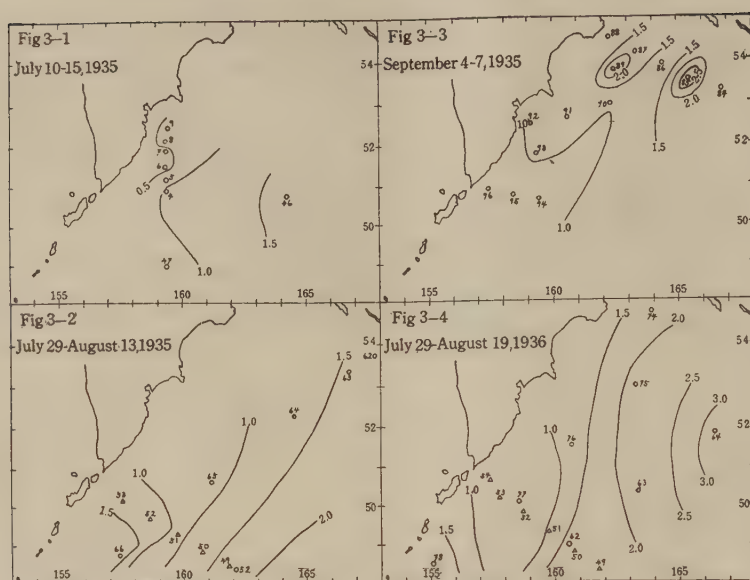


Fig. 3. Charts of temperatures in the 100m layer in the sea to the east off the northern Kurile Islands and the Kamchatka Peninsula.

Explanations are the same with Fig. 1.

Table 2. Data used in figs 3 and 4

Period	Ship	Station number	Figure
July 10 to 15, 1935	Komahashi Itsukushima	46, 47 4 - 9	Fig. 3 - 1, 4 - 1
July 29 to August 13, 1935	Komahashi Sōyō-maru	52, 62 - 66 48 - 53	Fig. 3 - 2, 4 - 2
September 4 to 7, 1935	Komahashi	84 - 96	Fig. 3 - 3, 4 - 3
July 29 to August 19, 1936	Komahashi Sōyō-maru	62 - 64, 74 - 78 49 - 54	Fig. 3 - 4, 4 - 4

As shown in Fig. 3, low temperature below 0.7°C is shown in a sea area lat. $50 - 52^{\circ}\text{N}$ and long. $158 - 159.5^{\circ}\text{E}$. This coldest water may be produced in winter in the coastal water of the southern Kamchatka Peninsula.

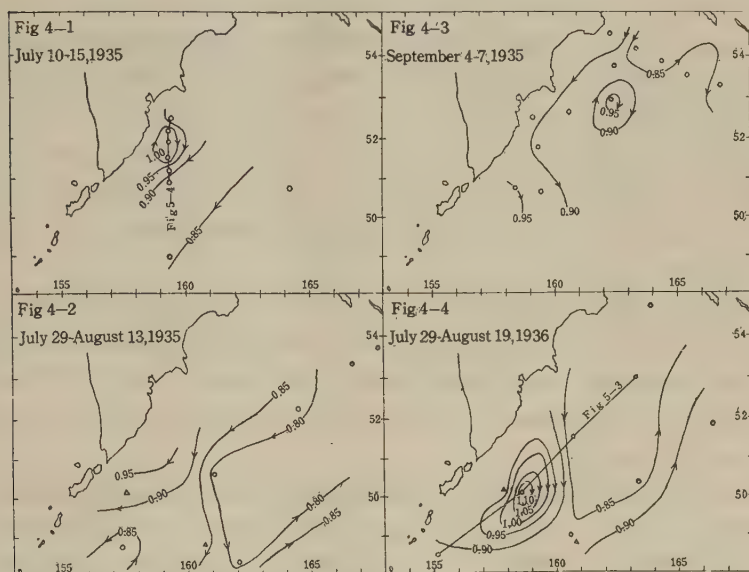


Fig. 4. Dynamic topographical charts relative to the 800 d.b. surface in the same sea with Fig. 3.

Explanation is the same with fig. 2.

In Fig. 4 a southward current is shown to the east of the coldest water above-mentioned. This current connects with the southwestward current off the southern Kurile Islands. A northeastward moving current is passing the vicinity of lat. 51°N and long. 163°E . Only in Fig. 4-3 a southwestward current from the Bering Sea is observed to the south of the strait between the east coast of the Kamchatka Peninsula and the Komandorskie Islands.

4. Computed velocity and volume transport of the southwestward current.

In Table 3 are shown the computed velocity and volume transport between pertinent pairs of stations in Figs. 2 and 4. In the sea to the south off Hokkaidō, the width of the strongest current of the Oyashio is only 10-15 miles (Sugiura 1957). Similar condition may be found also in the sea off the Kurile Islands, accordingly computed value of mean velocity between two stations may depend upon the interval of the stations, that is, large velocity may be given for a short interval and small one for a wide interval.

From Table 3, in the sea off the southern Kurile Islands (Fig. 2) the maximum surface velocity of the southwestward current relative to the 800 d.b. surface amounts to 13 cm/sec within an interval of 60 naut. miles, and 7cm/sec between stations 160 naut. miles apart. On the other hand in the sea off the northern Kurile Islands and the Kamchatka Peninsula (Fig. 4) maximum surface velocity of the southward current relative to the 800 d.b. surface amounts to 23 cm/sec between stations 20 naut. miles apart and 12 cm/sec between two stations 110 naut. miles apart.

As shown in Table 3 computed surface velocity relative to the 800 d.b. surface amounts, on the average, to about 60% of the velocity relative to the 1500 d.b. surface. The maximum value of computed surface velocity relative to the 1500 d.b. surface amounts to 21 cm/sec in an interval of 60 naut. miles in the southwestward current of Fig. 2-1.

Again from Table 3, computed volume transport of the southwestward current relative to the 800 d.b. surface amounts to 8~10 million m^3/sec in the sea off the southern Kurile Islands in Fig. 2. Corresponding value of the southward current off the northern Kurile Islands and the Kamchatka Peninsula in Fig. 4 amounts to 3~4 million m^3/sec on the average, but it amounts to about 10 million m^3/sec within the anticyclonic cold eddy which will be mentioned below in section 6.

Volume transport relative to the 800 d.b. surface in Fig. 2 amounts, on the average, to about 40% of the transport relative to the 1500 d.b. surface. The maximum value of computed volume transport relative to the 1500 d.b. surface amounts to 28 million m^3/sec between station 6 and 17 in Fig. 2-3.

5. *Cyclonic eddy to the east off the southern Kurile Islands*

Sometimes cyclonic eddies are observed between the southwestward current and the northeastward current mentioned in section 2. Two examples of them are observed with their centers at station 165 in Fig. 2-1 and at station 18 in Fig. 2-3.

In Fig. 5-1 are shown vertical distribution of σ_t and σ_t -temperature diagram within the former eddy. In the figure equi- σ_t surfaces of 27.0~27.6 are ascending to the shallower layer at station 165, but temperature on each equi- σ_t surface is almost constant around this station, in other words, this eddy is formed in a uniform water mass. The eddy near station 18 in Fig. 2-3 has similar character as shown in Fig. 5-2.

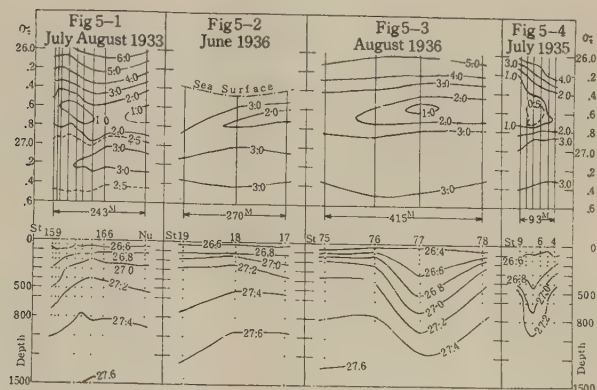


Fig. 5. Vertical distribution of σ_t (lower) and σ_t -temperature diagram (upper) along the sections within the eddies.
Numerals in the figure means σ_t (lower) and temperature (upper).

These eddies may have relation with the divergence of surface water due to the wind stresses (Hidaka 1955).

6. Anticyclonic cold eddy to the east off the northern Kurile Islands

In the sea off the northern Kurile Islands are observed anticyclonic cold eddies with their centers at station 7 in Fig. 4-1 and at station 77 in Fig. 4-4.

In Fig. 5-3, equi- σ_t surfaces of 26.6~27.4 are descending to the deeper layer at station 77 and temperature on the equi- σ_t surface of 26.6 takes the lowest value 0.8°C at this station. The eddy near station 7 in Fig. 4-1 has similar character as shown in Fig. 5-4, and at this station the temperature on the equi- σ_t surface of 26.6 is 0.0°C.

These eddies may be formed by the coldest water which is mentioned in section 3 and they move slowly to the south as will be shown in section 8.

7. Water masses flowing from the Okhotsk Sea and the Bering Sea

The currents which flow from the Okhotsk Sea through the straits between the Kurile Islands are not shown distinctly in the dynamic topographic charts Figs. 2 and 4 owing to want of adequate net of stations. But by the σ_t -temperature diagram the Okhotsk water can be detected at the following three stations to the south off the Urupp Straits.

Period	Ship	Station	Location	Figures
August 2, 1933	Komahashi	"He"	44°N 150.5°E	1-1, 2-1, 6-1
August 9, 1935	Komahashi	67	46°N 151.5°E	1-2, 2-2, 6-2
May 22, 1936	Komahashi	14	45°N 150°E	1-3, 2-3, 6-3

In Fig. 6-1 equi- σ_t surfaces of 26.8~27.6 are descending to the deeper layer near station "He", and temperatures on the equi- σ_t surfaces of 27.0~27.2 are lowest at this station, that is, the temperature is 2.2°C on the equi- σ_t surface of 27.1.

In Fig. 6-2 equi- σ_t surfaces of 26.4~26.8 and 27.4~27.6 are ascending to the shallower layer at station 67 and temperatures on the equi- σ_t surfaces of 26.9~27.3 are lowest at this station, that is, the temperature is 1.9°C on the equi- σ_t surface of 26.9 and 2.5°C on that of σ_t 27.3. At this station also the surface temperature is as low as 4.5°C in August.

In Fig. 6-3 temperatures on the equi- σ_t surfaces of 26.6~27.3 are lowest at station 14, that is, the temperature is 0.9°C on the equi- σ_t surface of 26.8 and 1.5°C on that of σ_t 27.1.

These three stations exhibit a distinctive character of the Okhotsk water, that is the temperature lower than 2.3°C on the equi- σ_t surface of 27.1.

Whether the current from the Okhotsk Sea flows uniformly at all seasons of the year or intermittently is not known yet.

As stated in section 3, a southwestward current from the Bering Sea was observed in September 1935 with its transport of 4 million m³/sec above 800m. Accordingly it may be certain that the current from the Bering Sea supplies a part of the southwestward current off the southern Kurile Islands. The current from the Bering Sea is rather warm near the Komandorskie Islands, but it becomes cold on the way to the south by mixing with the cold eddy mentioned in section 6.

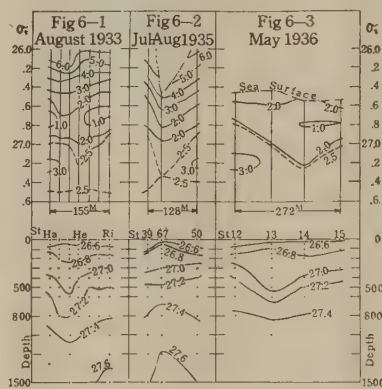


Fig. 6. Vertical distribution of σ_t (lower) and σ_t -temperature diagram (upper) along the section containing the Okhotsk water.

Explanations are the same with fig. 5.

8. *Seasonal variation in the same year*

Comparing Figs 1-3 and 1-4, temperature in the 100m layer rose as much as $0.0\sim 0.4^{\circ}\text{C}$ during 2.5 months from May to August 1936. Comparing Figs 2-3 and 2-4, the computed velocity of the southwestward current to the east of the Urupp Straits may be seen to have decreased to about half during the period of 2.5 months.

Comparing Figs. 4-1 and 4-3, in the sea to the east of the northern Kurile Islands the anticyclonic cold eddy is observed at a locality of lat. 52°N and long. 159.5°E in July 14 and at 50.5°N , 159.5°E in September 6. Accordingly the eddy moved to the south 75 naut. miles during 55 days.

9. *Summary*

(1) In the sea eastward off the Kurile Islands, existence of a southwestward moving current of the North Pacific Subarctic Water is ascertained by examination of dynamic topographical chart, and the velocity and transport of the current are computed.

This current joins the Oyashio Main Current to the south off Hokkaidō and the southward current to the east off southern Kamchatka Peninsula.

(2) To the southeast side of the southwestward current above mentioned a northeastward current of the North Pacific Subarctic Water flows corresponding to the Oyashio Counter Current to the south off Hokkaidō. Between the southwestward current and the northeastward one cyclonic eddies are observed.

(3) It is ascertained by σ_t -temperature diagram that the Okhotsk water which flows through the Urupp Straits supplies a part of the southwestward current.

(4) In the sea near southern Kamchatka, a mass of coldest water is observed with an anticyclonic eddy which moves slowly to the south in summer.

(5) The velocity and transport of the current from the Bering Sea flowing through the strait between the Kamchatka Peninsula and Komandorskie Islands are computed.

Acknowledgements: - In conclusion, the author wishes to express his thanks to Mr. Z. Yasui, Director of the Hakodate Marine Observatory for his continuous encouragement. Thanks are also due to Prof. Harold M. Lane of Hokkaidō University for reading the manuscript.

References

- Association of the Agricultural Technics (1954): Oceanographic data in the northern waters of the North Pacific.
- HIDAKA, K. (1955): Divergence of surface drift currents in terms of wind stresses, with special application to the location of upwelling and sinking. Jap. J. Geophys. 1, 47-56.
- Maritime Safety Agency (1950, 1951): The results of oceanographic observation in the north-western Pacific Ocean. No. 3, 4. Hydrogr. Bull., Special No. 6, 8.
- SUGIURA, J. (1957): On the Oyashio Current in the sea adjacent to Hokkaidō. Oceanogr. Mag., 9, 133-142.

Table 3. Computed velocity and volume transport.

Figure	Station	Date	Lat. N	Long E	Interval of the stations (naut. miles)	Mean velocity between stations		Volume transport	
						above 800m (cm/s)	above 1500m (cm/s)	above 800m ($10^6\text{m}^3/\text{s}$)	above 1500m ($10^6\text{m}^3/\text{s}$)
2—1	165 Ho	July 25 Aug. 2	43°-23' 44°-16'	149°-42' 150°-09'	56	13.3	20.6	7.5	15.9
2—2	49 50	July 26 "	43°-32' 44°-29'	147°-51' 150°-38'	135	4.0	—	3.1	—
2—3	1 17	May 10 June 2	42°-09' 44°-03'	146°-29' 151°-49'	260	3.7	6.5	7.5	22.7
"	6 17	May 20 June 2	48°-05' 44°-03'	153°-42' 151°-49'	254	4.2	7.6	10.5	28.2
"	13 18	May 22 June 2	46°-02' 44°-38'	151°-39' 154°-51'	159	7.1	—	10.0	—
2—4	60 14 ₂	July 27 Aug. 13	44°-10' 45°-09'	151°-53' 150°-09'	92	8.0	—	8.2	—
4—1	46 7	July 10 July 14	50°-49' 51°-54'	164°-12' 159°-18'	202	5.4	—	10.2	—
"	5 6	July 14 "	51°-12' 51°-32'	159°-10' 159°-28'	20	23.3	—	—	—
4—2	65 53	Aug. 7 Aug. 13	50°-41' 50°-07'	161°-06' 157°-30'	140	4.0	—	2.8	—
4—3	87 88	Sep. 4 Sep. 5	54°-12' 54°-33'	163°-25' 162°-14'	44	10.2	—	4.3	—
"	93 95	Sep. 6 "	51°-48' 50°-49'	159°-17' 158°-25'	70	3.9	—	2.6	—
4—4	61 77	July 28 Aug. 11	47°-35' 50°-06'	157°-45' 158°-32'	152	9.3	—	11.9	—
"	76 77	Aug. 10 Aug. 11	51°-32' 50°-06'	160°-42' 158°-32'	114	11.7	—	12.1	—

Vertical Distribution of Plankton at 40°N, 150°E in the Oyashio Water

Ryuzo MARUMO, Masataka KITOU and Mamoru OHWADA

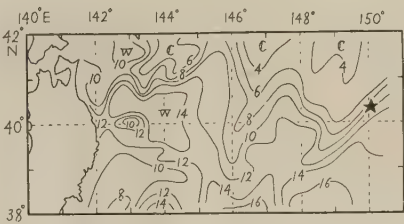
Japan Meteorological Agency

1. Introduction

To investigate the vertical distribution of diatoms, copepods, chaetognaths and pelagic larvae, two series of plankton collection were made at 40°18'N, 150°02'E in the Oyashio water on board the *Ryōfū-maru* at 1210-1330 on May 19, 1958 (Fig. 1). First, sea water samples for diatom investigation were obtained with Nansen bottles from 17 depths, i. e. from the depths of 0, 4, 8, 12, 15, 19, 23, 27, 31, 41, 46, 55, 64, 74, 92, 138 and 184m. Second, vertical hauls for zooplankton collection were made with a C-net (36cm in mouth diameter, mesh apertures of 0.33mm), one type of closing net, separately in the following five layers.

Length of wire (in m)	0-20	20-50	50-100	100-200	200-300
Inclination of wire	42°	30°	38°	48°	50°
Hauled layer (in m)	0-15	15-40	40-70	70-130	130-190

Fig. 1. The observational station and the distribution of surface water temperature.



2. Diatoms

The diatom community in this station was a typical one for the Oyashio water. Genus *Chaetoceros*, in which *Chaetoceros debilis* and *C. subsecundus* were most predominant, occupied about 90% of total diatom cells. Main diatoms identified are as follows.

<i>Chaetoceros atlanticus</i> Cleve	<i>Chaetoceros compressus</i> Lauder
<i>Chaetoceros debilis</i> Cleve	<i>Chaetoceros decipiens</i> Cleve
<i>Chaetoceros radicans</i> Schütt	<i>Chaetoceros subsecundus</i> (Grunow)
	Hustedt
<i>Corethron hystrix</i> Hensen	<i>Coscinodiscus stellaris</i> Roper
<i>Denticula</i> sp.	<i>Eucampia zodiacus</i> Ehrenberg
<i>Rhizosolenia alata</i> Brightwell	<i>Rhizosolenia hebetata</i> f. <i>semispina</i>
	(Hensen) Gran
<i>Stephanopyxis nipponica</i> Gran et Yendo	<i>Thalassiothrix longissima</i> Cleve et
	Grunow

There existed a distinct discontinuity of diatom populations between the depths of 46 and 55m (Fig. 2). Namely the cell number was 16,000 per liter at 46-m depth, and 300 at 55-m depth, about one fiftieth of that in the former depth. This distribution is considered to show that the diatom productive zone was situated in an upper layer of roughly 50-m depth. The discontinuity was almost not found in the distributions of water temperature and chlorinity between these layers, but there was a fairly large difference of dissolved oxygen contents, 0.7 cc/L, between them. In the upper 46-m layer, the cell number did not much fluctuate and was ranged from 16,000 to 65,000 per liter, and the diatom composition of each depth was also hardly variable. Vertical distributions of total diatoms, *Chaetoceros atlanticus*, *C. debilis* and *C. subsecundus* are shown in Fig. 2.

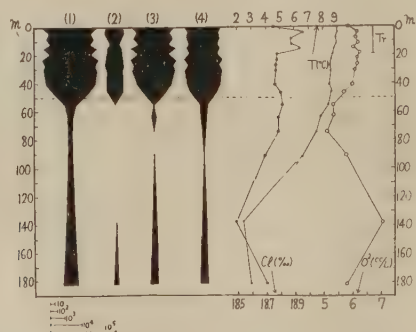


Fig. 2. Vertical distributions of diatoms per liter, water temperature (T), chlorinity (Cl), dissolved oxygen contents (O₂) and transparency (Tr). (1) Total diatoms, (2) *Chaetoceros atlanticus*, (3) *Chaetoceros debilis*, (4) *Chaetoceros subsecundus*.

3. Copepods

In five zooplankton samples, the majority was occupied by copepods, and the remainder consisted of a considerably large number of appendicularians and a few number of hydromedusae, chaetognaths, euphausiids, crustacean juveniles, pteropods, pelagic eggs and pelagic larvae of littoral animals.

The following 22 species of copepods were identified.

- | | |
|--|--|
| * <i>Calanus cristatus</i> Kröyer | <i>Calanus helgolandicus</i> (Claus) |
| * <i>Calanus plumchrus</i> Marukawa | <i>Calanus tenuicornis</i> Dana |
| * <i>Eucalanus bungii bungii</i> Johnson | <i>Eucalanus bungii californicus</i> Johnson |
| <i>Paracalanus parvus</i> (Claus) | * <i>Pseudocalanus minutus</i> (Kröyer) |
| * <i>Aetideus armatus</i> (Boeck) | <i>Euchirella rostrata</i> (Claus) |
| * <i>Pareuchaeta japonica</i> (Marukawa) | * <i>Scolecithricella minor</i> (Brady) |
| * <i>Racovitzanus antarcticus</i> Giesbrecht | |
| <i>Centropages abdominalis</i> Sato | * <i>Metridia lucens</i> Boeck |
| <i>Heterorhabdus papilliger</i> (Claus) | * <i>Acartia longiremis</i> (Lilljeborg) |
| ** <i>Oithona plumifera</i> Baird | <i>Oithona similis</i> Claus |
| ** <i>Oncaea media</i> Giesbrecht | ** <i>Corycaeus japonica</i> sp. nov. |

In this table, species marked with an asterisk have been reported as either cold-water or deep-water forms, and species with two asterisks as warm-water forms. *Calanus plumchrus*, *Eucalanus bungii bungii*, *Pseudocalanus minutus*, *Metridia lucens*, *Acartia longiremis* and *Oithona plumifera* were leading constituents of the copepod communities, of which vertical distributions are shown in Fig. 3.



Fig. 3. Vertical distributions of copepods per 10m³ sea water.

In immature forms of *Calanus plumchrus*, I—III copepodid stages were limited to be distributed in the upper 70-m layer, and they were most abundant,

amounting to about 1,000 individuals per 10m³ sea water, in the 0-15-m layer. On the other hand, IV-V copepodid stages appeared throughout all the layers, though in extremely small numbers. Adult forms were not collected at all, probably because the hauling layers were too shallow to get them. Motoda and Anraku (1951) stated that in Ishikari Bay the maximum density of immature forms of *Calanus plumchirus* was observed in the surface layer. This description agrees with the result of the present investigation made in the open sea.

Eucalanus bungii bungii occurred in a considerably large number in the upper 70-m layer, and the majority was occupied by I-III copepodid stages, which were found in this layer only. Vcopepodid stage occurred in all the layers, though not abundant. The number of adult was 3 individuals per 10m³ in the 15-40-m layer, 6 in the 70-130-m layer and 8 in the 130-190-m layer. Johnson (1930) stated that *Eucalanus bungii bungii* was a northern form of *Eucalanus bungii* and *Eucalanus bungii californicus* was a southern form of it. In the present investigation, *Eucalanus bungii californicus* appeared only in the 40-70-m layer in a small number.

Pseudocalanus minutus was extraordinarily abundant in the 0-15-m layer and decreased conspicuously in the lower 40-m layer.

Neither immature nor adult forms of *Metridia lucens* were collected in the 0-15-m layer, but 24 adults occurred in the layer below 130-m depth. This may be caused by the daytime collection which was made for this copepod having a remarkable habit of daily migration.

Acartia longiremis was abundant in the 0-15-m layer, but was not collected in the layer below 40-m depth. According to Minoda (1958), this species were predominant around Bower's Bank and in the eastern shallow water of the Bering Sea.

Oithona plumifera was not collected in the 0-15-m layer, but was found below 15-m depth, especially abundantly in the 40-70-m layer. This species is known to be widely distributed in offshore waters (Mori, 1937), while in Oshoro Bay this species is regarded as one of the copepods indicative of the Tsugaru warm current by the plankton table of Anraku (1953).

Calanus cristatus, *Pareuchaeta japonica*, *Scolecithricella minor*, *Raccovitzanus antarcticus* and *Aetideus armatus* were very scarce and their distributions were confined to below the 70-m depth.

This station is located in the Oyashio water, so that cold water species, such as *Calanus plumchirus*, *Eucalanus bungii bungii*, *Pseudocalanus minutus*, *Metridia lucens*

and *Acartia longiremis*, were predominant in the copepod communities. However, warm-water species, such as *Oithona plumifera*, *Oncaea media* and *Corycaeus japonica*, were also found, although the latter two species were relatively scarce. This fact will indicate that the Kuroshio water is spread northwards in the sea east of Honshū and mingled more or less with the Oyashio water in this station.

4. Chaetognaths

Eukrohnia hamata (Möbius), *Sagitta bedoti* Beraneck, *Sagitta elegans* Verrill, *Sagitta minima* Grassi and *Sagitta lyra* Krohn were identified.

As for *Sagitta elegans*, a typical chaetognath indicative of the Oyashio water, the individual number was 7 in the 0–15-m layer, and 2 in both of the 70–130 and 130–190-m layers.

Sagitta bedoti, *S. minima* and *S. lyra*, usually found in warm waters, were present in the upper 80-m layer.

Eukrohnia hamata was abundant, and amounted to 33 per 10m³ in the 70–130-m layer and 60 in the 130–190-m layer. According to Tokioka (1940), the inhabitancy of this chaetognath is the surface layer in the Arctic and Antarctic sea areas and the deeper layer in the tropical areas. One of the authors always found this species in the upper 100-m layer of the Oyashio water around Japan in May from 1955 to 1957.

5. Pelagic larvae of littoral animals

Actinotrocha, trochophora, echinopluteus and ophiuroid larvae were found.

Ophiuroid larvae were numerous and showed a characteristic vertical distribution. As shown in Table 1, early ophiopluteus stages (Fig. 4A) were present in the upper 70-m layer, more developed ophiopluteus



Fig. 4. Microphotograph of the larvae of Ophiuroidea.

stages (Fig. 4B) in the 15—70-m layer, and ophiuroid post-larvae (Fig. 4C) in the 15—70 and 130—190-m layers. In short, the more the stage advances, the more deeply the inhabitancy goes down. This vertical distribution seems to show that a larva continues to develop with sinking to deeper layers.

Table 1. Individual numbers of ophiuroid larvae per 10m³.

Number \ Layer (in meter)	0—15	15—40	40—70	70—130	130—190
Early ophiopluteus stages	7	30	17	—	—
More developed ophiopluteus stages	—	13	7	—	—
Ophiuroid post-larvae	—	7	11	—	3

6. Summary

Vertical distributions of diatoms, copepods, chaetognaths and pelagic larvae of littoral animals were investigated at a station of the Oyashio water.

1. The diatom productive zone was the layers above the 50-m depth.
2. I—III copepodid stages of *Calanus plumchrus* and *Eucalanus bungii bungii* were found only in the upper 70-m layer.
3. The more the stage of ophiuroid larva advances, the more deeply the inhabitancy goes down.

References

- ANRAKU, M. (1953): Seasonal distribution of pelagic copepods at Oshoro Bay, west coast of Hokkaido, Bull. Fac. Fish., Hokkaido Univ., 3(3).
- JOHNSON, M. W. (1939): The study of species formation in certain Eucalanus copepods in the North Pacific, Proc. Sixth Pac. Scin. Cong., 3.
- MINODA, T. (1958): Report from the "Oshoro Maru" on oceanographic and biological investigation in the Bering Sea and Northern North Pacific in the summer of 1955, V Observations on copepods community, Bull. Fac., Fish., Hokkaido Univ., 8(4).
- MORI, T. (1937): The pelagic Copepoda from the neighbouring waters of Japan, Yōkendō, Tokyo.
- MOTODA, S. and M. Anraku (1951): An observation on the vertical distribution of plankton at Ishikari Bay, Hokkaido, Jour. Oceanogr. Soc. Japan, 6(4).
- TOKIOKA, T. (1940): Fauna Nipponica, Phylum Chaetognatha, 5(11) (in Japanese), Sanseidō Tokyo.

Relation between the velocity and the location of the front of the Kuroshio off the Tôhoku district

TOSIO NAN'NITI

Meteorological Research Institute

Abstract: Some dynamical calculation about the Kuroshio and the Oyashio current was made, and the relation between the velocity and the location of their front off the Tôhoku district is studied. The phenomena of front are very complicated, and they have not a definite relation between them but the front is formed at some location irrespective of the velocity of Kuroshio.

1. Introduction

It is very important to forecast the oceanic conditions to study the location of the front of the Kuroshio off the Tôhoku district. If the relationship of the initial current velocity at Bôsô peninsula and the location of the front was looked for, it may be easy to forecast the oceanic conditions. The following method was applied to this study as equal as in my previous paper (Nan'niti 1958) to calculate the dynamical properties of the Kuroshio and the Oyashio.

2. Numerical calculation

The result referred from the previous paper is

$$\begin{aligned}\rho &= \rho_b - \Delta \rho e^{k\{h(x) - x\}} \\ h(x) &= h(\infty) (1 - e^{-\alpha x}) \\ v(x) &= \sqrt{g \frac{\Delta \rho}{\rho} h(\infty)} \cdot e^{-\alpha x} \\ &= ce^{-\alpha x}\end{aligned}$$

where

$$\alpha = f/c$$

The x -coordinate is cross-stream pointing to southward and the y axis is equal to 42°N line.

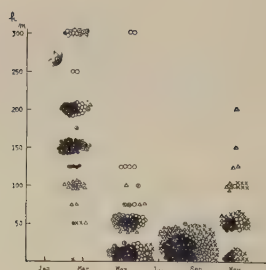


Fig. 1. Seasonal variation of thickness h of the top layer of uniform density. Symbols: ●Oyashio water, × coastal water, △ mixed water with Kuroshio and Oyashio, ⊙Northern Kuroshio water, ○Southern Kuroshio water.

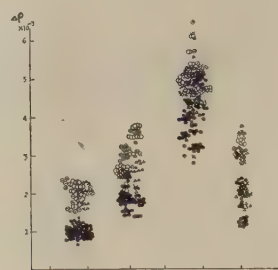
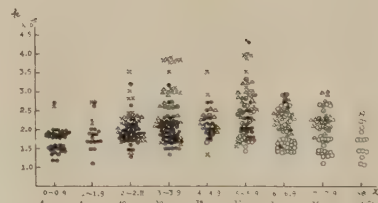


Fig. 2. Seasonal variation of $\Delta\rho$. Symbols are the same as explained in Fig. 1.

Fig. 3. Mean value of k as functions of location x° , or water masses. Symbols are the same as explained in the above figures.



The figures of density structure or h , $\Delta\rho$, k are shown in Figs. 1, 2 and 3. The top layer of uniform density, h , and the density difference, $\Delta\rho$, show seasonal variation, and they are estimated as follows

Table 1. Mean values of $h(\infty)$ and $\Delta\rho$

	month	$h(\infty)^m$	$\Delta\rho \times 10^{-3}$
Kuroshio	{February March	200	2
	{August September	25	5
Oyashio	{February March	150	1
	{August September	25	4

So the ratio of maximum velocity in spring and summer is $C_{\text{summer}}/C_{\text{spring}}=0.6$ in the Kuroshio and $=0.8$ in the Oyashio. The observed mean value from 1924 to 1934 shown in the current chart of the North Pacific Ocean (chart No. 6031) published by the Maritime Safety Agency is as follows.

T. Nan'niti: Relation between the velocity and the location of the front

Table 2. Mean maximum velocity of the Kuroshio off Tiôsi, Bôsô peninsula, from 1924 to 1934.

month	max. vel. (kt)	location where the Kuroshio can reach
Dec. Jan. Feb. Mar.	2.5}	N 37° parallel
Apr. May	2.8}	
Jun. Jul. Aug. Sep.	2.0}	N 35° parallel
Oct. Nov.	1.6}	

So the ratio of maximum speed is $C_{\text{summer}}/C_{\text{spring}} = 0.8$. At any rate, the current speed in the summer decreases about 20 percents than in the spring.

The mean vertical distribution of density ρ of each water mass is shown in Fig. 4 and from the figure we have the following Table 3.

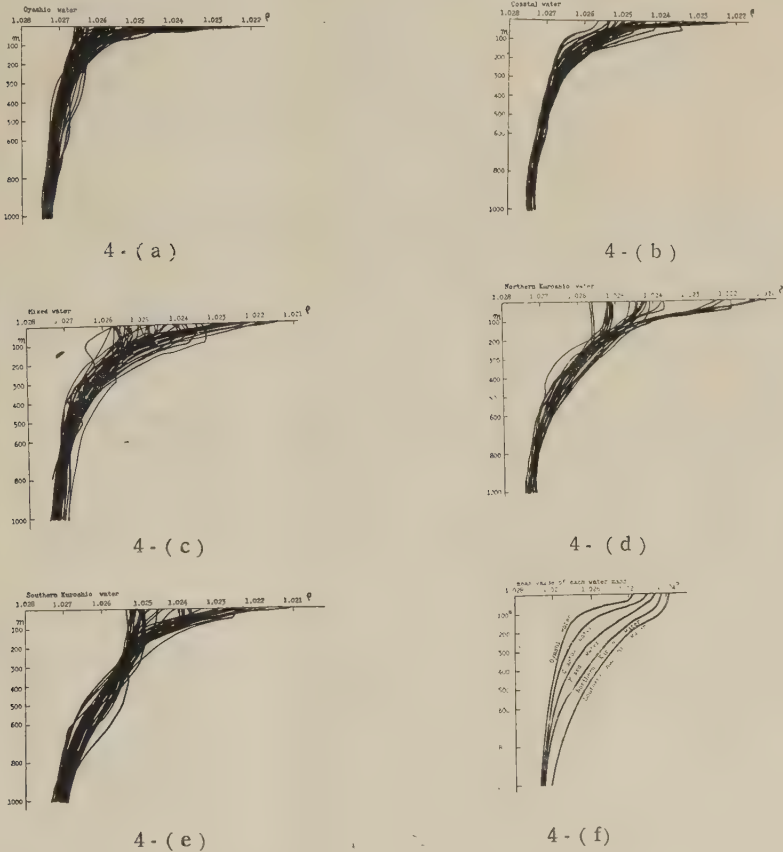


Fig. 4. Mean vertical distribution of density of each water mass. (a~f)

Table 3. Mean value of the character of each water mass.

Water mass	x°	ρ_θ	$\Delta\rho(10^{-8})$	$h(m)$	$k(10^{-6})$	Symbols
Oyashio	0~6	1.02745	2.6	150	1.932	●
Coastal water	—	1.0274	2.95	—	2.224	×
Mixed water	2~7.9	1.02735	3.05	75	2.385	△
Northern Kuroshio	4~7.9	1.0273	3.1	150~300	2.289	⊙
Southern Kuroshio	6~>8	1.0271	3.15	200~300	1.865	○

Putting the above result, we have the maximum velocity of the Kuroshio and the Oyashio in March as follows:

$$\text{Kuroshio} \quad C = \sqrt{980 \times \frac{0.002}{1.027} \times 20000} = 195.4 \text{ cm/sec}$$

$$\alpha = 4.61 \times 10^{-7} [1/\text{cm}] = 4.19 [1/\text{deg}]$$

$$\text{Oyashio} \quad C = \sqrt{980 \times \frac{0.001}{1.027} \times 15000} = 119.6 \text{ cm/sec}$$

By the above equations, the theoretical thickness of the top layer h and the velocity of the Kuroshio along the cross-stream section v are shown in Table 4.

Table 4. The thickness of the top layer of uniform density and current velocity.

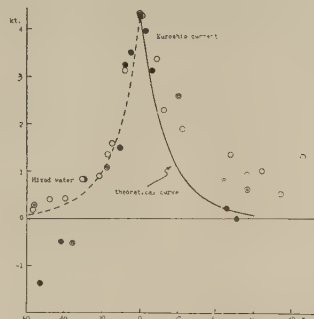
x°	0.0	0.05	0.1	0.2	0.3	0.5	0.7	0.76	1.0	∞
$h(x)^m$	0.0	36	68	114	144	176	188	192	196	200
v^{kt}	4.25	3.49	2.81	1.83	1.19	0.51	0.26	0.17	0.09	0.0

The comparison of calculated and observed velocity along the cross-stream section is shown in Fig. 5. The date observed in Nov. 1956 is in good agreement with the theoretical one, but the other two values observed in August 1954 and 1955 are not. And they are all in better agreement at the left boundary, though the theoretical one is for the right boundary. The maximum anticyclonic shear is $\partial v / \partial x = f$ at $x = 0$.

Now we estimate the velocity, V kt, of the Kuroshio at the offing of Bôssô peninsula (35°N) and the location of its front which is measured the distance in

T. Nan'niti: Relation between the velocity and the location of the front

Fig. 5. Comparison of calculated and observed velocity along the cross-stream section. Symbols: ○ Aug. 1954 by R.S. "Kaiyô Maru No. 4", ⊙ Aug. 1955 by R.S. "Ryôfû Maru,". ● Nov. 1956 by R.S. "Ryôfû Maru".



degree, X° , from the 35°N line and the velocity of the Kuroshio v kt at the front off the Tôhoku district.

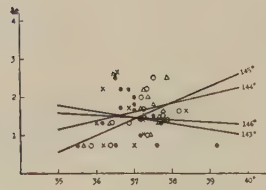
Table 5. Current velocity and location of front on the each meridional line.

year	month	Bôsô pen. (35°N) vel. V max. mean	on meridional lines							
			143°E locX vel.v	144°E locX vel.v	145°E locX vel.v	146°E locX vel.v	147°E locX vel.v	148°E locX vel.v	149°E locX vel.v	150°E locX vel.v
1954	Mar.	1.0kt 0.7kt	$33^\circ30'$ 1.5kt	$35^\circ40'$ 2.0kt	$35^\circ50'$ 1.2kt	$36^\circ10'$ 1.0kt	—	—	—	—
	May~ Jun.	1.0 0.7	3630 2.8	—	3620 2.0	3700 2.2	$36^\circ40'$ 2.5kt	$36^\circ50'$ 4.9	$37^\circ15'$ 2.5kt	—
	Aug.~ Sep.	1.8 1.3	3610 3.3	3260 1.6	3620 2.2	3600 2.0	3540 1.4	3555 2.5	3625 2.0	—
	Nov.	— —	3645 2.5	3700 4.9	3655 2.8	3620 2.8	3615 2.8	3610 4.9	—	—
1955	Feb.~ Mar.	1.8 1.3	3740 1.8	3740 3.3	3650 2.0	—	3600 2.8	3600 1.5	3555 2.2	$35^\circ50'$ 3.3kt
	May	3.0 2.5	3630 2.0	3750 3.5	3730 3.9	—	—	3530 2.5	3615 2.5	3620 3.0
	Aug.	1.6 1.4	3710 3.2	3745 2.9	3750 4.5	3710 3.4	3700 4.1	3830 2.3	3830 1.6	3610 4.0
	Nov.	2.5 1.6	3700 1.2	3745 2.5	3810 3.3	3820 2.8	3825 2.5	3700 2.2	—	3725 1.5
1956	Feb.~ Mar.	3.1 1.7	3640 1.3	3710 2.5	3710 2.0	3650 2.0	3650 2.0	3655 1.6	3705 1.5	—
	May	1.5 1.0	3710 2.3	3725 3.6	3720 1.9	3715 2.3	3615 4.4	—	—	—
	Jun.	3.0 2.2	3640 3.2	3715 3.2	3715 3.3	—	—	—	—	—
	Sep.	2.8 1.7	—	—	3710 1.9	—	3610 3.8	—	—	3625 2.4
	Nov.	3.5 1.8	3700 1.5	3730 2.7	—	—	3710 1.2	—	—	—
1957	Jun.~ Jul.	1.8 1.5	3730 2.4	3740 3.1	3745 2.9	3715 4.0	3635 2.8	—	—	—
	Aug.	3.9 2.2	3650 1.1	—	—	3610 3.5	3600 2.8	—	—	—
1958	Mar.	3.0 2.6	—	3630 2.6	—	3630 3.4	—	3500 3.4	—	3540 3.8

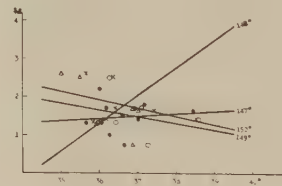
The relations between the velocity of Kuroshio, V kt, and their location X° off the Tôhoku district along the each meridional lines are as follows and shown in Fig 6.

Table 6. Relation between the velocity V kt and location X° .

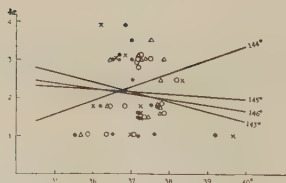
on 143°E line	$V \text{ mean} = 1.8 - 0.2X^\circ \pm 0.4$ $V \text{ max.} = 2.7 - 0.3X^\circ \pm 0.7$
on 144°E line	$V \text{ mean} = 1.2 + 0.2X^\circ \pm 0.4$ $V \text{ max.} = 1.6 + 0.4X^\circ \pm 0.5$
on 145°E line	$V \text{ mean} = 0.6 + 0.4X^\circ \pm 0.3$ $V \text{ max.} = 2.3 - 0.1X^\circ \pm 0.6$
on 146°E line	$V \text{ mean} = 1.6 - 0.1X^\circ \pm 0.4$ $V \text{ max.} = 2.4 - 0.1X^\circ \pm 0.7$
on 147°E line	$V \text{ mean} = 1.4 + 0.1X^\circ \pm 0.3$ $V \text{ max.} = 2.1 + 0.1X^\circ \pm 0.7$
on 148°E line	$V \text{ mean} = 0.6 + 0.7X^\circ \pm 1.0$ $V \text{ max.} = 2.7 - 0.3X^\circ \pm 0.5$
on 149°E line	$V \text{ mean} = 1.8 - 0.2X^\circ \pm 0.5$ $V \text{ max.} = 2.5 - 0.3X^\circ \pm 0.6$
on 150°E line	$V \text{ mean} = 2.1 - 0.2X^\circ \pm 0.4$ $V \text{ max.} = 2.4 + 0.1X^\circ \pm 0.5$



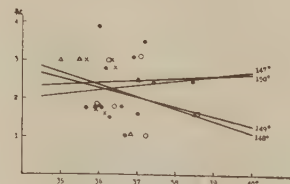
6 - (a)



6 - (b)



6 - (c)



6 - (d)

Fig. 6. Relation between velocity of Kuroshio at the offing of Bôshô peninsula and locations of front on the each meridional lines.

a.b Relation between mean velocity and location

c.d Relation between maximum velocity and location

Symbols: a,c ● 143, △ 144, ○ 145, × 146

b,d ● 147, △ 148, ○ 149, × 150

T. Nan'niti: Relation between the velocity and the location of the front

Further the relations between the locations of the front X° and the velocity of current at the front v_{kt} along the each meridional lines are as follows and shown in Fig. 7.

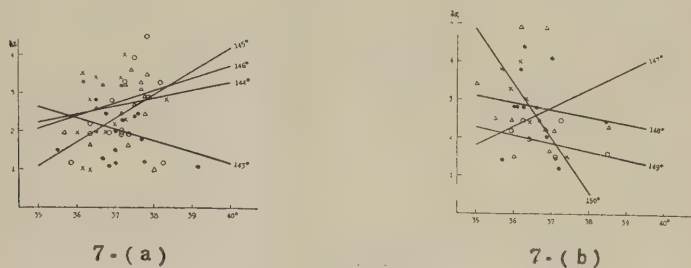


Fig. 7. Relation between location of front and velocity of current at the front.
Symbols are the same as explained in Fig. 6. (a~b)

Table 7. Relation between velocity v_{kt} and location of front X° .

143°E line	$v = 2.6 - 0.3X^\circ \pm 0.5$
144°E line	$v = 2.2 + 0.2X^\circ \pm 0.7$
145°E line	$v = 1.1 + 0.6X^\circ \pm 0.6$
146°E line	$v = 2.1 + 0.3X^\circ \pm 0.6$
147°E line	$v = 1.8 + 0.5X^\circ \pm 0.8$
148°E line	$v = 3.1 - 0.2X^\circ \pm 0.9$
149°E line	$v = 2.3 - 0.2X^\circ \pm 0.3$
150°E line	$v = 4.9 - 1.4X^\circ \pm 0.4$

From the above results, we can hardly find the systematic relation between the current velocity and the location of Kuroshio front; the location of front is irrespective of current velocity. An equal conclusion we get by studying the

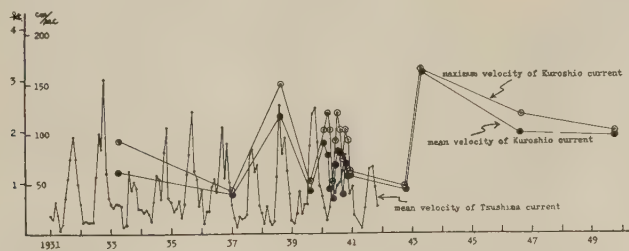


Fig. 8. Relation between the velocity of Kuroshio off the Ōsumi peninsula and the Tsushima current.

Oyashio and its front, though their data are less scarce than the Kuroshio. So it is not reasonable that, as we say, when the Kuroshio is strong, the front will move to a northern location, and vice versa.

Same as the above, the relation between the velocity of Kuroshio off the Ôsumi peninsula (Hydrographic chart No. 195) and Tsushima current (Hidaka and Suzuki 1950) was shown in Fig. 8. The correlation coefficient of each month, 12 readings, in 1940 is only $r = -0.22$. The significant points of 5% and 10% for 12 readings are $r = 0.53$ and 0.45 , so the above correlation value $r = -0.22$ is not significant. When the negative sign of correlation becomes significant, it means that the Kuroshio will not run with the equal velocity at the both sides of Kiûsiû but will choose one favorite path either of them at the point of Kiûsiû. What a cause does determine the path of the Kuroshio?

References

- HIDAKA, K. and T. SUZUKI 1950; Secular Variation of the Tsushima Current (in Japanese). Journ. Oceanogr. Mag. 6 (1) 28—31
- NAN'NITI, T. 1958; A Theory of the Mechanism of the Generation of the Cold Water Region in the Offing of Enshûnada. Pap. Met. Geophys 8 (4) 317—331

Distribution of Plankton Copepods at the Ocean Weather Station "X", May 1950 to April 1951

By

Masataka KITOU

Japan Meteorological Agency

1. Introduction

Plankton collections were carried out by the ocean weather ships of the Central Meteorological Observatory at the Ocean Weather Station "X" (39° N, 153° E) in the three years from 1950 to 1952. The collections were made by vertical haul from 100-metre depth to the surface with Kitahara's quantitative nets (of Hensen type, 22.5 cm in mouth diameter, mesh apertures of 0.11 mm). Kitou and Asaoka (1956, 1957) have already reported on the seasonal variation of phytoplankton, and Marumo and others (1954) on the standing crops of main plankton groups at this station. The present paper describes the monthly variation of main copepods and the distribution of copepods, with reference to oceanographic conditions based on the samples collected in a period from May 1950 to April 1951. In other periods species of copepods were not identified.

2. Monthly variation of copepods

As for the monthly mean number of copepods including nauplii, there were three peaks in the curved line, and they were present in May and November 1950, and in March 1951. Throughout 82 times of the net hauls, the largest number, 21347 individuals, was in May, while the least, 640 individuals, was in June. As for the monthly composition of copepod communities, nauplii and young stages of copepodid were predominant components, and *Oithona similis* was next to them. The monthly mean number of copepods including nauplii and the monthly composition of copepod communities are shown in Fig. 1 and in Table 1, respectively. It is noticeable that the composition of copepod communities at the station was extremely uniform throughout the year.

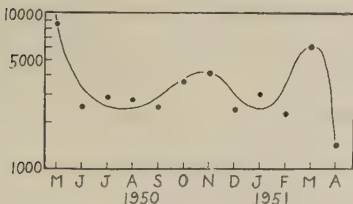


Fig. 1. Average numbers of copepods in 1 m³ of sea water for each month; plotted logarithmically.

Table 1. Composition of copepod communities in the period from May 1950 to April 1951.

Month Number of net haul	May 13	June 3	July 11	Aug. 13	Sep. 8	Oct. 5	Nov. 2	Dec. 4	Jan.~ Feb. 6	Mar. 9	Apr. 3
	%	%	%	%	%	%	%	%	%	%	%
Copepod juv.	81	86	84	83	80	81	73	81	80	81	75
<i>Oithona similis</i>	15	12	12	14	11	10	18	17	17	16	16
Copepod miscs.	4	2	4	3	9	9	9	2	3	3	9

The copepods identified from the above-mentioned materials are as follows:

<i>Calanus cristatus</i> Kroyer	<i>Euchirella rostrata</i> Giesbrecht
<i>C. darwinii</i> (Lubbock)	<i>Euchaeta marina</i> Prestandrea
<i>C. gracilis</i> (Dana)	<i>Pareuchaeta flava</i> Mori
<i>C. helgolandicus</i> (Claus)	<i>Pareuchaeta japonica</i> (Marukawa)
<i>C. minor</i> (Claus)	<i>Scolecithrix danae</i> (Lubbock)
<i>C. pauper</i> Giesbrecht	<i>Temora discaudata</i> Giesbrecht
<i>C. plumchrus</i> Marukawa	<i>Metridia lucens</i> Boeck
<i>C. robustior</i> Giesbrecht	<i>Pleuromamma abdominalis</i> (Lubbock)
<i>C. tenuicornis</i> (Dana)	<i>P. gracilis</i> (Claus)
<i>C. vulgaris</i> (Dana)	<i>P. xiphias</i> Giesbrecht
<i>Eucalanus attenuatus</i> (Dana)	<i>Heterorhabdus papilliger</i> (Claus)
<i>E. giesbrechti</i> sp. nov.	<i>Candacia bipinnata</i> (Giesbrecht)
<i>E. crassus</i> Giesbrecht	<i>C. pectinata</i> Brady
<i>E. elongatus</i> (Dana)	<i>C. truncata</i> (Dana)
<i>E. subcrassus</i> Giesbrecht	<i>Pontelopsis</i> sp.
<i>E. subtenuis</i> Giesbrecht	<i>Acartia negligens</i> Dana
<i>Rhincalanus cornutus</i> Dana	<i>Oithona nana</i> Giesbrecht
<i>R. nasutus</i> Giesbrecht	<i>O. plumifera</i> Baird
<i>Mecynocera clausi</i> Thompson	<i>O. similis</i> Claus
<i>Paracalanus aculeatus</i> Giesbrecht	<i>Microsetella norvegica</i> (Boeck)
<i>P. parvus</i> Giesbrecht	<i>M. rosea</i> (Dana)
<i>Acrocalanus gibber</i> Giesbrecht	<i>Oncaea media</i> Giesbrecht
<i>A. gracilis</i> Giesbrecht	<i>O. venusta</i> Philippi
<i>Clausocalanus arcuicornis</i> (Dana)	<i>Sapphirina auronitens</i> Claus
<i>C. peregens</i> Farran	<i>S. nigromaculata</i> Claus
<i>Ctenocalanus vanus</i> Giesbrecht	<i>S. intestinata</i> Giesbrecht

The monthly variation of *Clausocalanus arcuicornis* and *Clausocalanus pergens* was in a close agreement with that of the species mentioned above.

Genus *Sapphirina* and *Euchaeta marina* occurred in May, July, March and April, and *Paracalanus aculeatus* occurred in June with a relatively high frequency of appearance. These three are tropical forms.

Paracalanus parvus and *Microsetella norvegica* whose distribution is known to be neritic occurred in the period from May to November. The former had a low frequency of appearance in general, and the latter a high frequency in the period from August to November.

Calanus helgolandicus, which is widely distributed in middle latitudes, occurred often at the station.

Euchirella rostrata, a deep water species, appeared concentrically in spring season.

3. Correlation between principal species of copepods and oceanographic conditions.

1. Regarding the distribution of copepods, it is most noteworthy that *Oithona similis* was identified from all samples in a relatively constant percentage on monthly average. Tanaka (1957) stated that *Oithona similis* was the commonest of the cosmopolitan species. However, this species was distributed usually in the sea areas north of the Kuroshio Main current in the western North Pacific,

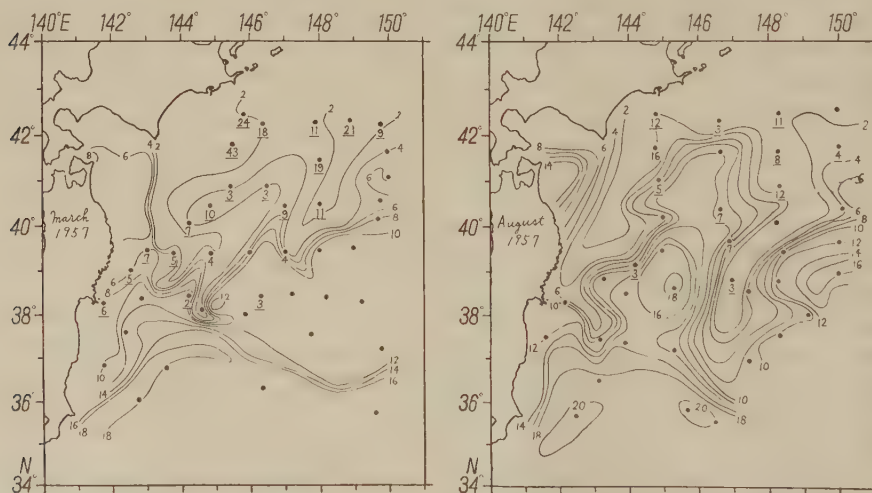


Fig. 2. Percentage of *Oithona similis* to the total number of copepods and water temperature at 100-metre depth in March and August 1957.

M. Kitou: Distribution of Plankton Copepods at the Ocean Weather Station "X", etc.

according to the data of the survey by Japan Meteorological Agency (1955-58). As an example, the distributional patterns of *Oithona similis* in March and August 1957 are shown in Fig. 2. Minoda (1958)

also stated that *Oithona similis* was collected in the largest number off the eastern coast of Kamchatka. Therefore, *Oithona similis* is regarded as one of the copepods indicative of the Oyashio in the western North Pacific. Thus, it is considered that the waters above the 100-metre depth in the said station have been more or less mingled with the Oyashio cold water, although in most cases temperature and chlorinity did not directly indicate their influence. The distributions of water temperature and chlorinity at 25-metre depth are shown in Fig. 3.

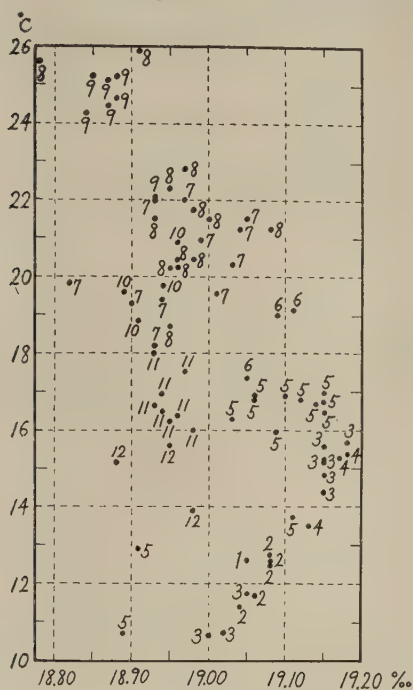


Fig. 3. Water temperature and chlorinity at 25-metre depth at the stations made net haul. Numerals in the figure denote months.

2. The highest water temperature, about 25°C, at 25-metre depth appeared in August. However, the frequent occurrence of the majority of warm water species mentioned in the preceding chapter was about two months later than August, and they disappeared in the period from December to February, in

which water temperature at 25-metre depth was relatively low. Kokubo (1946-50) observed that the occurrence of oceanic warm water species chiefly depended upon the effect of the Tsushima warm current in Aomori Bay, and Anraku (1953) stated also that the same result was seen in Ishikari Bay. In the cases of both the bays, the predominant occurrence of warm water species was observed in autumn, and was about two months later than the period of the highest temperature. Concerning the distribution of warm water species, the same tendency was observed in the said station, and then it may be deduced that the Kuroshio surface water is extremely prevailing in the season of autumn in the vicinity of this station. Among warm water species, *Sapphirina* spp. and *Euchaeta marina* occurred in the period from March to July, in which chlorinity was high, conspicuously in May at the 25-metre and 100-metre depths. The distribution of these species seems to be ruled not only by water temperature but also by chlorinity. It is

unknown why the majority of warm water species disappeared in June when the values of water temperature and chlorinity were relatively high.

3. On the tolerance of the Oyashio species, such as *Calanus plumchrus* and *Calanus cristatus*, in the Kuroshio water.

As shown in Table 3, the said station was obviously covered by the Oyashio

Table 3. Occurrence of *Calanus cristatus*, *Calanus plumchrus* and *Sapphirina* spp. and the distribution of water temperature and chlorinity in the period from May 10 to 20.

Date	May	10	11	12	15	16	17	18	19	20
Water temperature (°C)	25 m	12.90	10.74	13.76	16.52	15.96	16.73	16.78	16.92	16.93
	100 m	9.93	9.47	9.99	14.66	13.62	14.57	12.83	14.67	11.98
Chlorinity (‰)	25 m	19.01	18.89	19.11	19.15	19.09	19.14	19.15	19.10	19.06
	100 m	18.95	18.92	18.96	19.15	19.10	19.12	19.06	19.13	19.05
<i>Calanus cristatus</i>		+	+	+	—	+	+	—	—	+
<i>Calanus plumchrus</i>		+	+	+	+	+	+	—	—	+
<i>Sapphirina</i> spp.		—	—	—	—	+	—	+	+	+

water in the three days from May 10 to 12, and *Calanus cristatus* and *Calanus plumchrus* occurred continuously in these days. After that, though the station was covered by the Kuroshio water, both the species were still conserved in it. Thus, we may consider that, although the mingling of the Oyashio water was not seen from the data of temperature and chlorinity, it is indicated by the presence of the two species. This phenomenon is available for guessing the career of the Kuroshio water in the nearest past in the vicinity of the Polar frontal zone.

Acknowledgement—The author wishes to express his hearty thanks to Dr. R. Marumo for his advice and suggestion.

Summary

1. The monthly mean number of copepods increased in May, November and March. Nauplii and young stages of copepodids were predominant in number, and *Oithona similis* were next to them.
2. The successive appearance of *Oithona similis* in a range from 11 to 18 % to the total number of copepods suggests that the station was always influenced more or less by the Oyashio water, though the affection was not seen clearly from water temperature or chlorinity.
3. Many warm water species, such as *Calanus minor*, *Eucalanus elongatus*, *Eucalanus subtennis*, *Mecynocera clausi*, *Scolecithrix danae*, *Oncaea media* and

M. Kitou: Distribution of Plankton Copepods at the Ocean Weather Station "X", etc., *Oncaea venusta*, frequently appeared in the period from September to November, namely about two months later than the period when water temperature at 25-metre depth was highest. This phenomenon indicates that the Kuroshio water is most prevalent in autumn at the station.

4. *Calanus cristatus* and *Calanus plumchrus* seem to be the species useful to know the influence of the Oyashio water upon the Kuroshio warm water, because they were conserved in the Kuroshio water for some time after the encounter of both the waters, although the influence was not clearly seen from water temperature and chlorinity.

References

- KITOU, M. and ASAOKA, O., (1956, 1957): Seasonal Variation of Phytoplankton at the Ocean Weather Station "X" (1950-1952)-1, 2 (in Japanese). Jour. Oceanogr. Soc. Japan, **12**, 4., **13**, 1.
- MARUMO, R., KITOU, M. and ASAOKA, O. (1954): The Productivity and Its Seasonal Variations of Marine Plankton Groups in the Open Sea (in Japanese). Jour. Oceanogr. Soc. Japan, **10**, 4.
- TANAKA, O. (1957): Papers of Scientific Fisheries (Suisangaku-zenshu) (in Japanese). Tokyo University.
- Japan Meteorological Agency (1955-58): The Results of Marine Meteorological and Oceanographical Observations. 16-22.
- MINODA, T. (1958): Report from the "OSHOROMARU" on Oceanographic and Biological Investigations in the Bering Sea and Northern North Pacific in the Summer of 1955. Bull. Fac. Fish., Hokkaido Univ., **8**, 4.
- ANRAKU, M. (1953): Seasonal Distribution of Pelagic Copepods at Oshoro Bay, West Coast of Hokkaido. Bull. Fac. Fish., Hokkaido Univ., **3**, 3.
- KOKUBO, S. (1946-1950): Bulletin of the Marine Biological Station of Asamushi. **1-5** (**1-4** in Japanese).

The Variations of the Kuroshio Current in the Sea south and east of Honshu (Japanese Main Island)

By

Jiro FUKUOKA

(Meteorological Research Institute, Tokyo)

Abstract:—In the present paper a discussion was made on the appearance of the cold water mass east of Miyake-jima and on the meandering of the Kuroshio east of Honshu (Japanese Main Island). The author studied the relation between the existence of the cold water mass and the meandering of the Kuroshio east of Honshu, and explained that the meandering was due to planetary waves.

§ *Preface*

The author (1958) has already discussed the variation of the Kuroshio current near the Izu Islands. The aim of this paper is to discuss the bottom effect on the Kuroshio which flows over the Izu submarine ridge. This phenomenon seems to be similar jet stream over the mountain. But, according to the latest research, some new phenomena about the deflection of the Kuroshio have been found.

The author intends to report these new phenomena and the variations of the Kuroshio east of Honshu (east of Cape Inubo (Inubo-zaki)) which connect with the deflection of the Kuroshio south of Honshu.

§ *About the Kuroshio near the Izu Islands*

Referring to current charts and water temperature distributions, the Kuroshio which flows to rightward against the advance direction, seems to stream around the large cold water mass.

This large cold water mass occupies about 70 nautical miles (130 Km) east of Miyake-jima and constructs the cyclonic circulation. (For positions of island see Fig. 1) The dimension of the cold water mass is about 60 nautical miles in diameter and the thickness of it reaches 800 m, according to the result of observations made by the Hydrographic Department. When the Kuroshio meanders east of Miyake-jima, the cold water mass always occupies in this area. (Fig. 1)

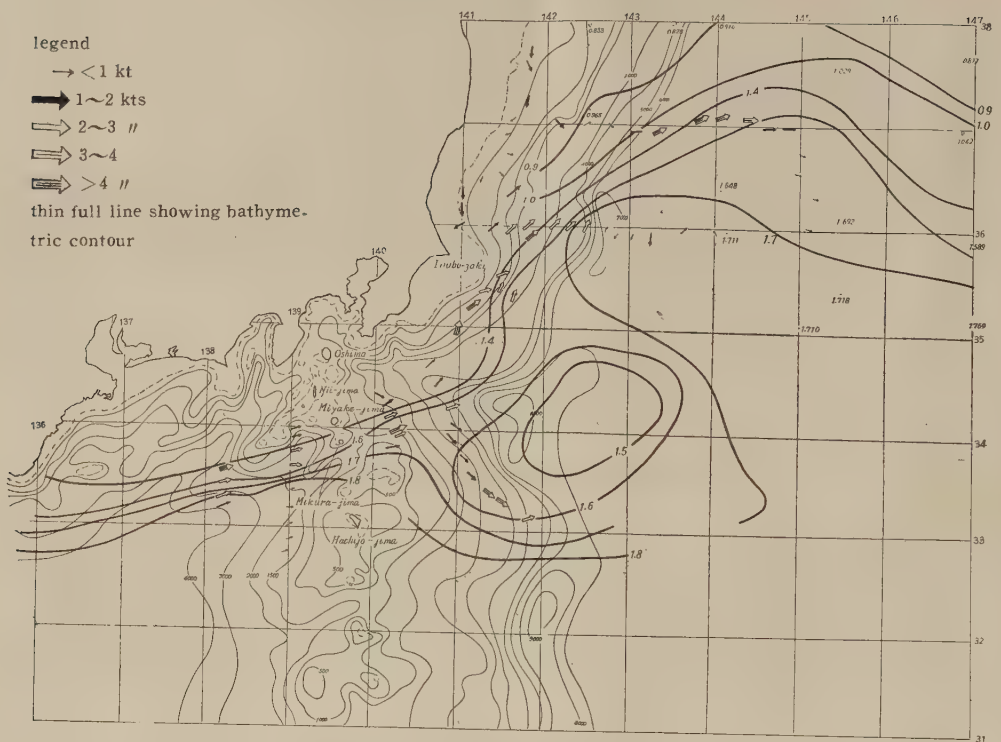


Fig. 1a Dynamical topography (0—600 db) and Current measurement by GEK (Aug. 1956)

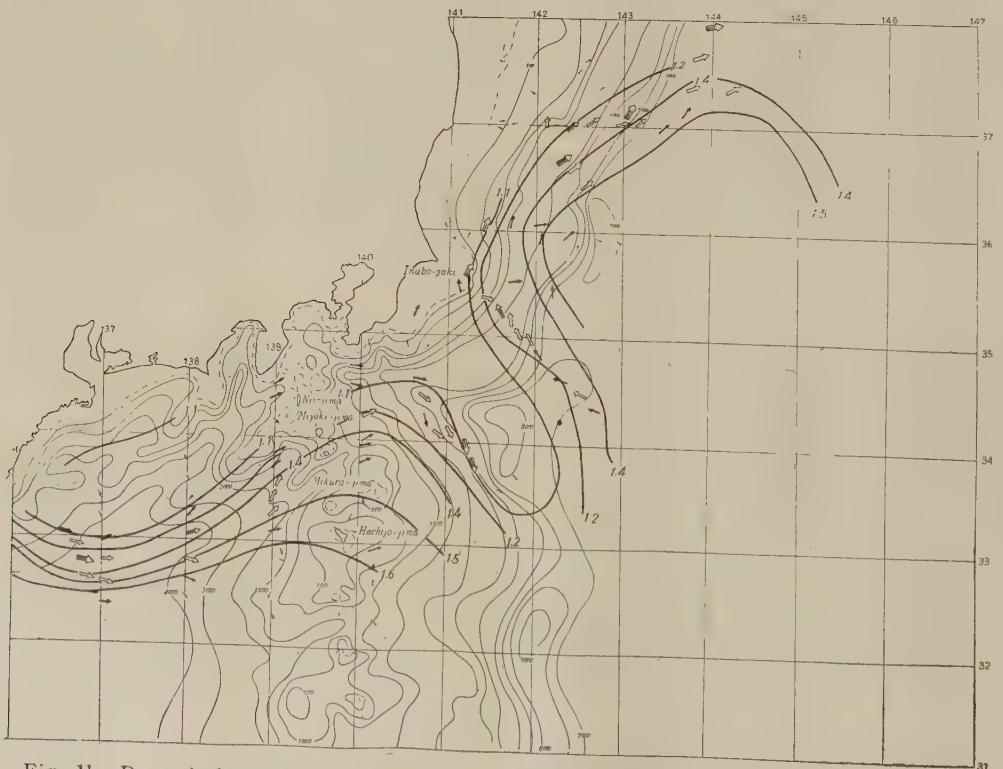


Fig. 1b Dynamical topography (0—600 db) and current measurements by GEK (May, 1957)

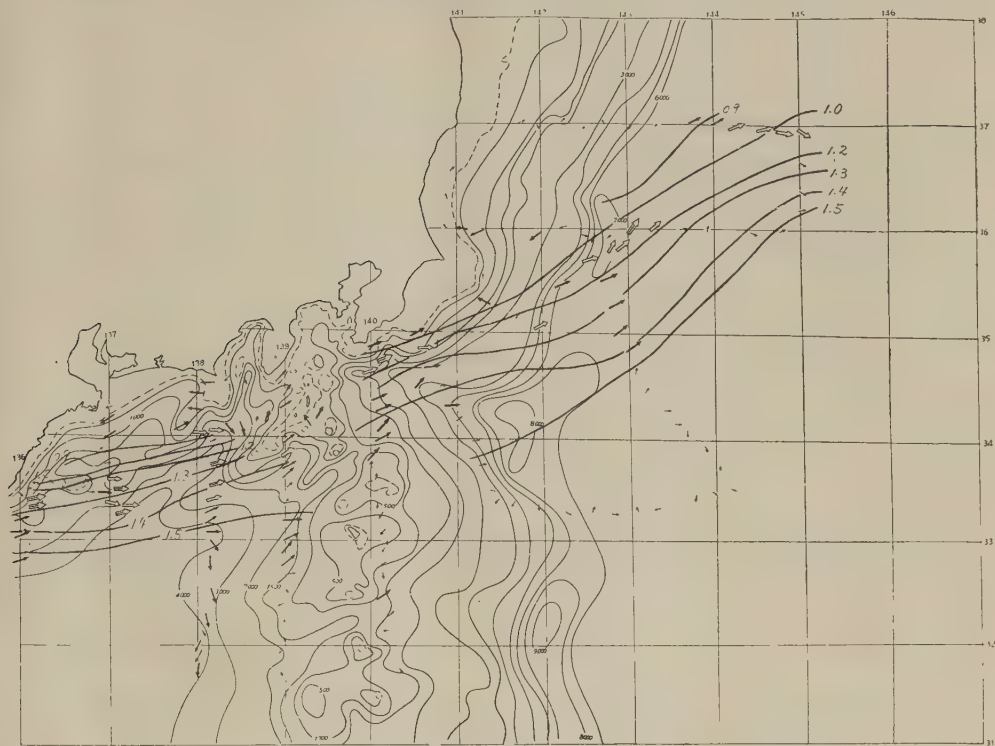


Fig. 2a Dynamical topography (0—600 db) and current measurement by GEK (Mar. 1958)

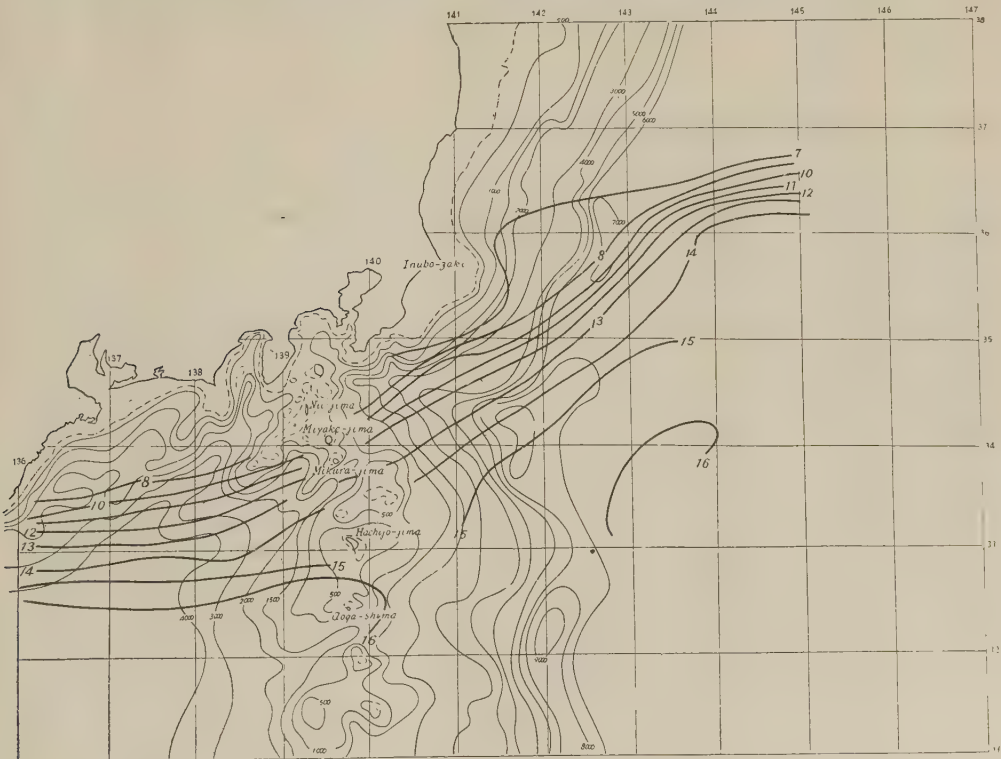


Fig. 2b Water temp. on the 400 m layer (Mar. 1958)

We often found the meandering of the Kuroshio east of the Izu Islands and the appearance of the cold water mass in the past time. (Uda 1938)

The author's idea about the meandering of the Kuroshio near the Izu Islands was dependent upon the submarine ridge effect, but the effective fact opposing against the explanation of the effect by the submarine ridge has been found.

Water temperature distribution and flow patterns of ocean current are shown in Fig. 2 which are based upon the observations carried out by the Hydrographic Department in March 1958. Referring to these charts, we can see that the Kuroshio streams in almost straight line from west to east near Miyake-jima. In west of Miyake-jima the current velocity of the Kuroshio is very swift, being more than 3 knots. When we discuss only from the date of surface current, the flow patterns of the Kuroshio west of the Izu Islands could not be seen the significant difference among three males, that is, August 1956, May 1957 and March 1958. It is said that the flow pattern of August 1956 west of the Izu Islands is similar to that of March 1958. In spite of these similar flow patterns, the Kuroshio of August 1956 meandered widely east of Miyake-jima but that of March 1958 without meandering streamed in almost straight line toward ENE east of Miyake-jima. So the author has questioned the appearance of the current deflection by the effect of submarine ridge.

§ *The cold water mass east of the Izu Islands*

The cold water mass east of the Izu Islands has been briefly explained in the above chapter. The author would like to study the occurrence of the cold water mass on basis of data of 1956 and 1957.

Especially, in August 1956 the cold water mass occupied distinctly. Referring to Fig. 3, low temperature area is seen remarkably at the depths of 400 m and 600 m. The area of the cold water mass constructs the cyclonic circulation on the dynamical chart. When we study the distribution of surface current by GEK, it is very similar to the flow pattern by dynamical calculation. (Fig. 1) When we study the surface current in the northern part of this area in August 1956, the ocean currents along the coast of Tohoku District always have southward direction and rather swift velocity (about 1 knot).

In order to research the origin of the southward current, coastal water temperatures at the northern part of Tohoku District and Hokkaido along the Pacific side were studied. In July and August 1956 water temperatures of the above

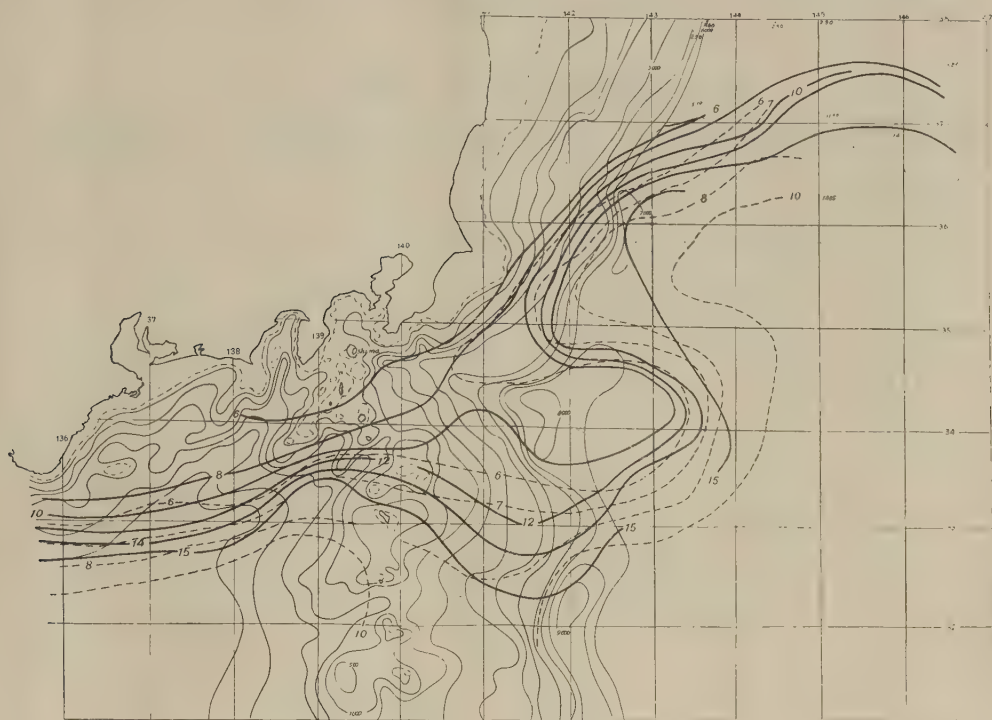


Fig. 3a Water temp. on the 400 m and the 600 m layers
(Aug. 1956 — Water temp. of 400 m Water temp. of 600 m)

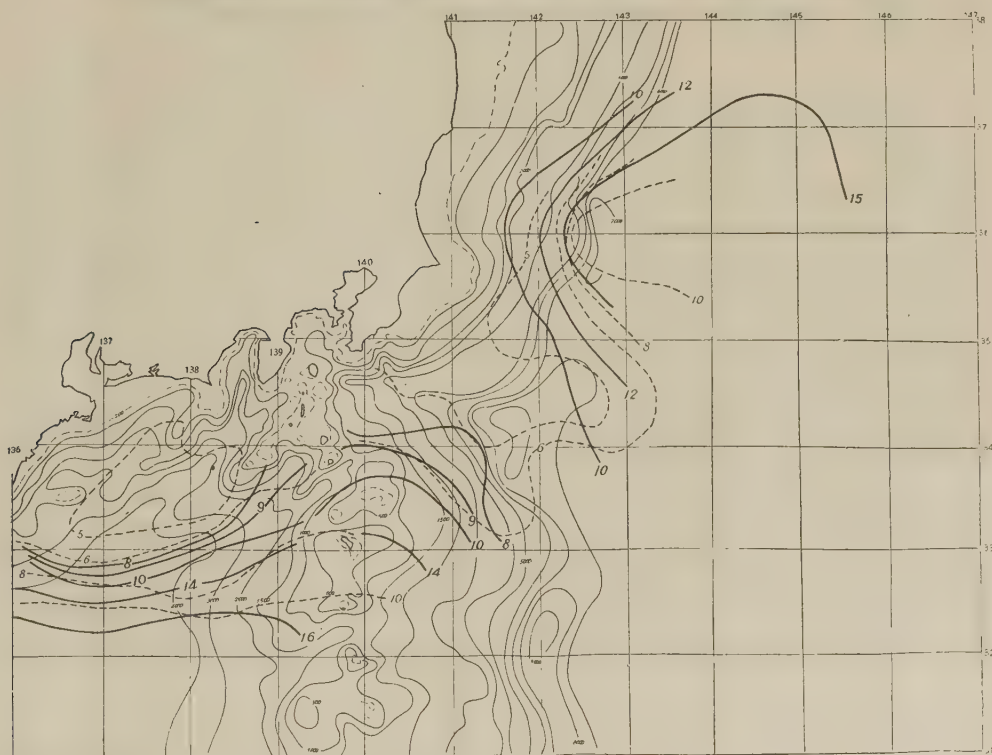


Fig. 3b Water temp. on the 400 m and 600 m layers
(May, 1957 — 400 m 600 m)

stated stations were very low, that is, about 2°C lower than the mean state. (Fig. 4)

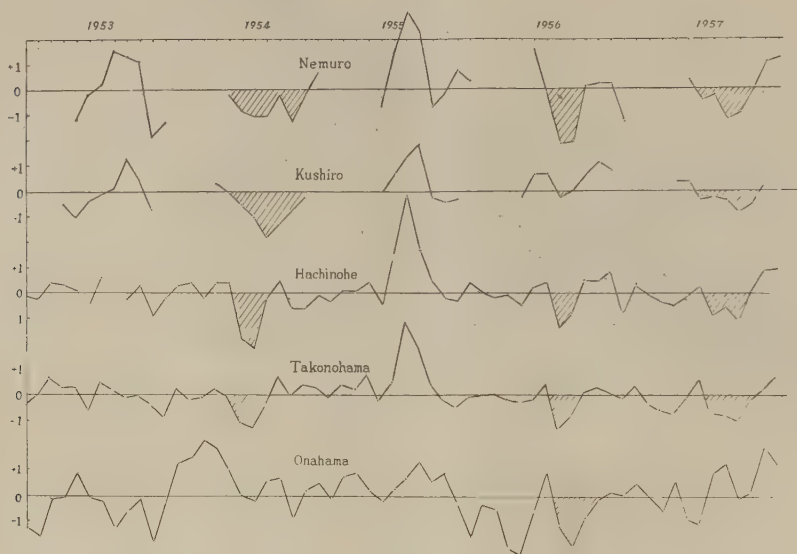


Fig. 4 Departures of monthly mean water temperatures in selected Stations.
(Shadow line showing low temperature in almost Stations)

The characteristics of the southward current in August 1956 is low temperature and rather swift velocity. Next, we study how much the southward current transports. From Fig. 1, we can notice that the coastal Oyashio current has the width of 20 nautical miles (37 km) and the depth of 500 m by T-CI curves. The mean current velocity from the surface to 500 m depth is assumed to be 0.5 knots (25 cm/s). If the Oyashio stated above continues for a month, this transportation value is $11.6 \times 10^{12} \text{m}^3$. On the other hand, the volume of the cold water mass is $12.6 \times 10^{12} \text{m}^3$, assuming that the cold water mass forms a cylinder with diameter of 100 km and the depth of 800 m.

From the above estimation, if the southward current is staying at some place and then constructing the cold water mass and mixing does not happen, the completion of the cold water mass should be necessary for the duration of a month. Could we not see the dominant cold water mass such as stated above before August 1956? Referring to the observational data of May 1956, the cold water mass did not occupy east of Miyake-jima. We could not find the cold water mass, but in the remote distance, that is, near 35°N , 144°E , the dominant southward motion

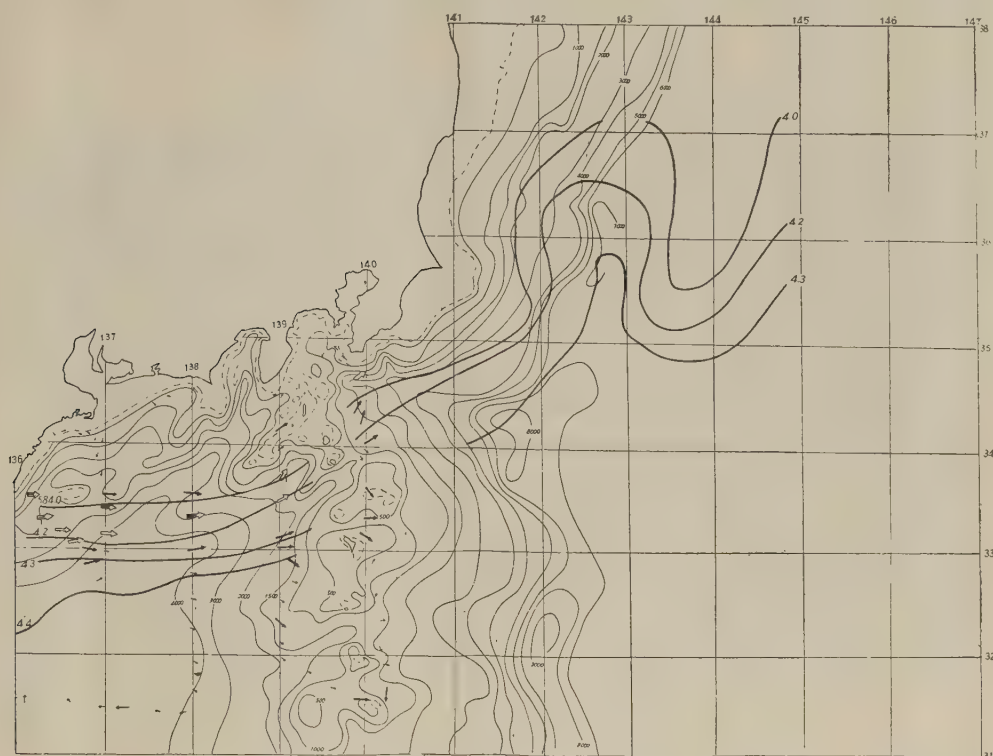


Fig. 5a Dynamical topography (0–600 db) and current measurements by GEK (May, 1956)

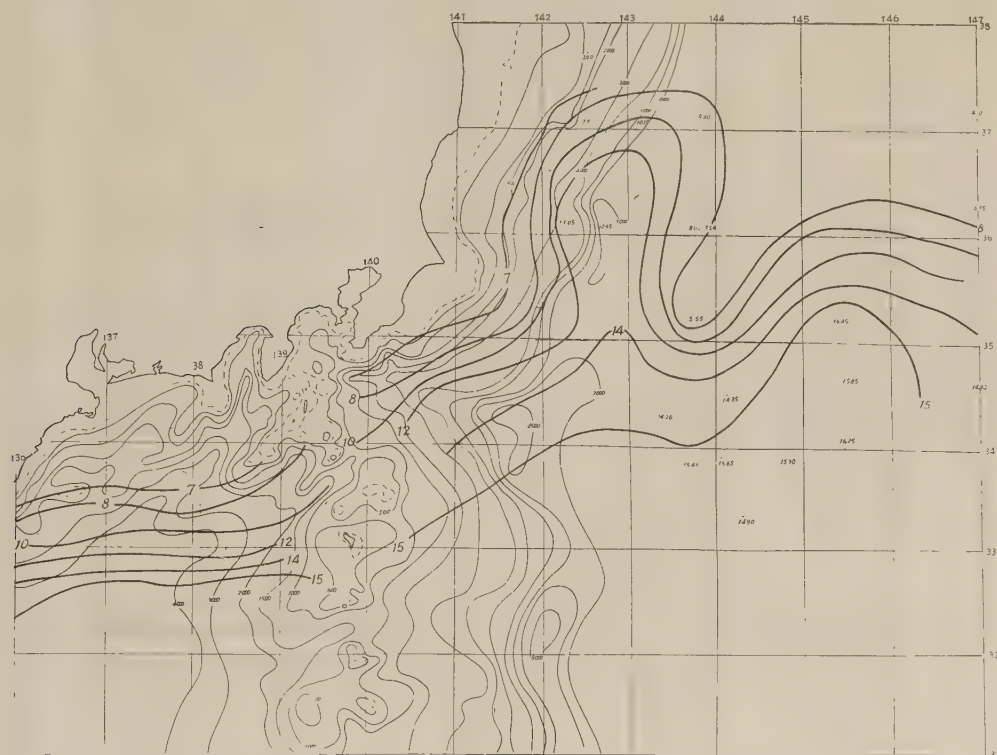


Fig. 5b Water temp. on the 400 m layer (May, 1956)

of the cold water on 400 m and 600 m water temperature distributions. (Fig. 5)

Although both flow patterns in 1956 and 1958 by GEK have not difference west of the Izu Islands, the fact which the Kuroshio does not meander east of Miyakejima in 1958 must indicate that the explanation to occur this meandering in the Kuroshio only due to the effect of the submarine ridge is not sufficient. So we should notice the existence of the cold water mass. How long is the life time of this cold water mass, since the appearance of it? From August 1956 to May 1957 twice oceanographical observations were carried out in November 1956 and March 1957. For all fourth observations we can find the cold water mass. In August 1957 this water mass reduced, but the trace of it could be seen. (Fig. 6) Of course, the supply of the Oyashio current to the cold water mass should be considered continuously all interval. But it may be seen that the life time of the cold water mass is about 13 months. The origin of the cold water mass is regarded as the southward motion of the Oyashio along the coast of Tohoku. But

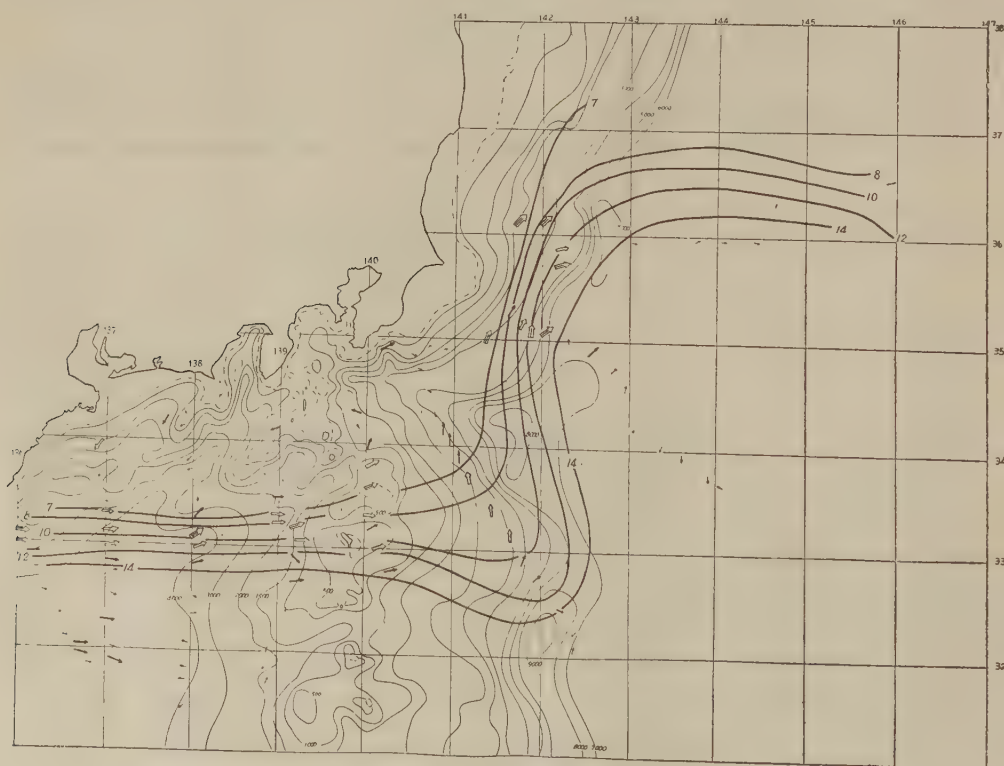


Fig. 6 400 m water temperature and current measurements by GEK (Aug. 1957)

J. Fukuoka: The Variations of the Kuroshio Current in the Sea south and east of Honshu the cold water mass was often seen off shore. (Fig. 5) For example, in May 1956 the cold water mass was found off shore and it is considered that the cold water moves toward south and so occupies east of Miyake-jima.

It is not certain whether the origin of the cold water mass is due to the southward motion of the coastal Oyashio current or of the off-shore Oyashio. It is necessary to study the distinct origin of the cold water mass in future.

Next, it should be studied whether or not the phenomena of the cold water and the Kuroshio meandering east of Miyake-jima were noticed in the past. Before the Second World War oceanographical observations were not often carried out in the sea area under consideration, that is, east of the Izu Islands. After the War, the observation of this sea area also was not excersized frequently. By the reference of a few data, in June 1950 the Kuroshio over the Izu submarine ridge meandered indistinctly, but in 1951 the meandering of the Kuroshio was not seen at all. (Fig. 7) The Kuroshio meandering in June 1950 is not so remarkable as in

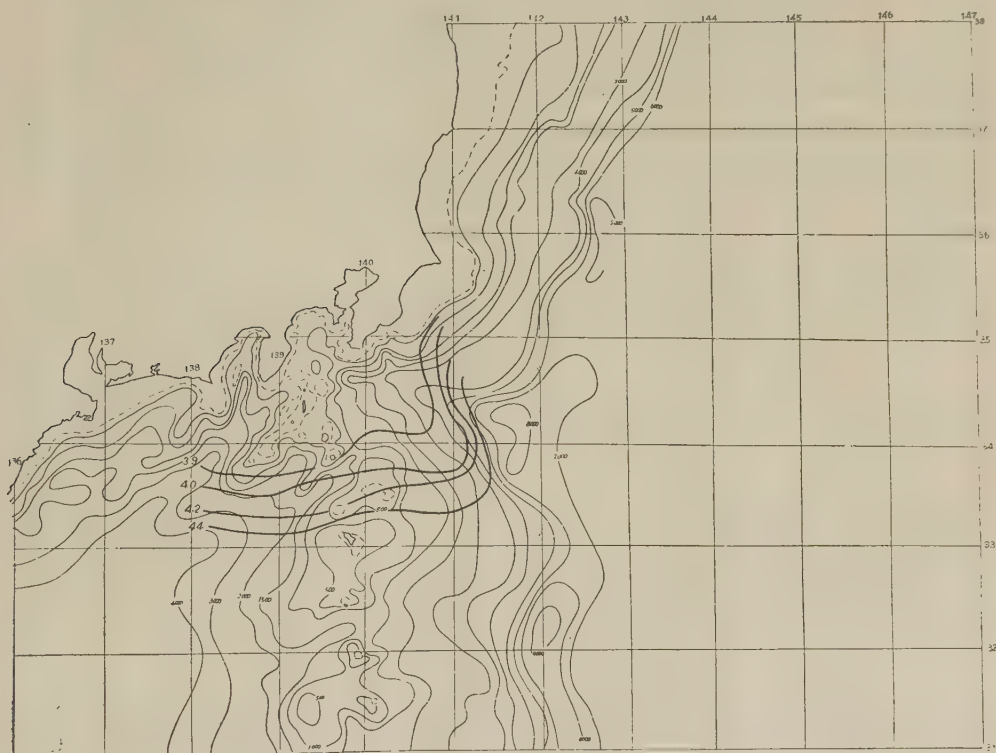


Fig. 7 Dynamical topography (0—600 db) (June 18~July 4, 1950)

August 1956. It is not decided whether the indistinct meandering is in progress or indicates phenomena in the time of decay of the cold water mass.

When we study the coastal water temperature at Tohoku and Hokkaido along the Pacific side, the rather lower water temperatures than mean state are seen in June 1949. It may be seen that the lowering of coastal water temperature may be connected with the existence of the cold water mass, but this relation is not clear. The water temperature lowering in 1949 is not so noticeable as in 1956.

§ *The Kuroshio main current east of Honshu*

The above discussions were mainly delivered about the appearance and duration of the cold water mass. In the following, the author studies the variations of the zone of the Kuroshio main current which may be dependent upon the existence of the cold water mass east of Miyake-jima. When we decided the path of the Kuroshio main current from May 1956 to August 1957, it is shown in Fig. 1. The paths of the Kuroshio in November 1957 and March 1958 are shown in Fig. 2. The paths of the latter differ remarkably from them in the former. In the case of the existence of the cold water mass east of Miyake-jima, the Kuroshio near Inubo-zaki streams toward north in almost straight line but unless, it flows toward north-east or east-north-east. The Kuroshio of the former reaches more northward than of the latter. ICHIYE (1957) already studied the meandering of the warm current [related the growth of the warm water mass east of Tohoku.

Following ICHIYE's paper these phenomena are considered below. ROSSBY (1940) introduced the expression which vorticity transport is constant.

$$fV + \frac{M}{R} = \text{const} \quad \left\{ \begin{array}{l} \text{Where } f \text{ Coriolis parameter, } V \text{ volume} \\ \text{transport of current unit depth, } M \\ \text{momentum transport per unit depth, } R \\ \text{radius of curvature of the stream line,} \\ x \text{ eastward, } y \text{ northward} \end{array} \right.$$

The vorticity transport of narrow, straight west wind current is given by the expression $f_0 V$, f_0 being the value of the Coriolis parameter at latitude of the current axis ($y=0$).

The vorticity transport in this same region has the value as follows:

$$fV + \frac{M}{R} = (f_0 + \beta y) V + \frac{M}{R} \quad \left(\beta = \frac{\partial f}{\partial y} \right)$$

As y increases $1/R$ must decrease and finally vanish (inflexion point). The initial cyclonic vorticity of the perturbation is seen checked by the increasing

J. Fukuoka, : The Variations of the Kuroshio Current in the Sea south and east of Honshu
 anticyclonic vorticity associated with the northward displacement. The differential equation for this stable perturbation pattern is best obtained by shifting the origin ($y=0$) to the mean position of the disturbed current. This mean position must obviously coincide with the inflexion point to the current. Thus,

$$fV + \frac{M}{R} = f_0V$$

is the equation for the current, provided R is positive for cyclonic curvature, negative for anticyclonic. From this equation it follows that

$$\beta yV + \frac{M}{R} = 0 \quad \text{where} \quad -\frac{1}{R} = \frac{d^2y}{dx^2} \left[1 + \left(\frac{dy}{dx} \right)^2 \right]^{-\frac{3}{2}}$$

The extreme case is provided by current intersecting the axis at right angles. It then follows that

$$\begin{aligned} \frac{dy}{dx} &= \infty & \text{for } y=0 \\ \frac{\beta V}{M} y_0^2 &= 2 & y_0 = 1.414 \sqrt{\frac{\bar{c}}{\beta}} \quad \left(\text{for } \bar{c} = \frac{M}{V} \right) \end{aligned}$$

(where y_0 signifies the northmost displacement of the current from its mean state)

A quarter of a wave length is obtained by integration between $y=0$ and $y=y_0$. The result is

$$L = 4y_0 \int_0^1 \frac{s^2}{\sqrt{1-s^4}} ds = 5.656 \sqrt{\frac{\bar{c}}{\beta}} \int_0^1 \frac{s^2}{\sqrt{1-s^4}} ds = 3.39 \sqrt{\frac{\bar{c}}{\beta}} \quad \text{where } s = \frac{y}{y_0}$$

As the Kuroshio streams to north in almost straight line east of Inubo-zaki, there is a cold water mass east of Miyake-jima. We can regard this case as $\frac{dy}{dx} = \infty$. Values of y_0 and L are obtained at 36°N as shown in Fig. 1.

$$y_0 = 232 \text{ km} \quad L = 557 \text{ km} \quad (\beta = 1.825 \times 10^{-13} \quad \bar{c} = 50 \text{ cm/s})$$

When the Kuroshio off Inubo-zaki streams to north-east or east-north-east, we have $\frac{dy}{dx} = \alpha$ in $y=0$.

In this case $L = 2\pi \sqrt{\frac{\bar{c}}{\beta}}$

$$L = 1033 \text{ km} \quad (\beta = 1.852 \times 10^{-13} \quad \bar{c} = 50 \text{ cm/s})$$

Where $\frac{dy}{dx} = \frac{1}{2}$ (for $y=0$)
 $y_0 = 75 \text{ km}$

In the former we can see that the wave length L and amplitude y_0 are 660 km and 200 km, respectively by the data of May 1957 which are considered as the

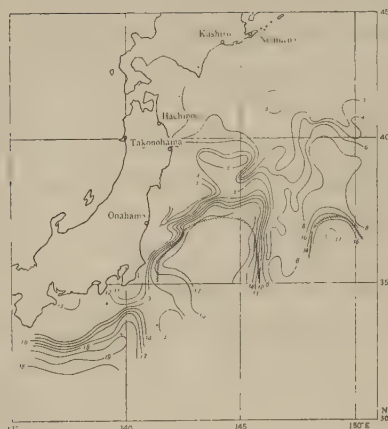


Fig. 8a The Kuroshio path and 200 m water temperature of May 1957
 — Kuroshio path



Fig. 8b The Kuroshio path and 200 m water temperature of Mar. 1958
 — Kuroshio path

typical pattern of the northward Kuroshio. (Fig. 8a) The example of the latter is the observation of March 1958. In March 1958 a half wave length is merely observed, but by observation $1/2 L$ is 500 km and y is 110 km. Calculation is to be in accord with observation. (Fig. 8b)

§ Problem in future

In the above sections we have discussed the meandering of the Kuroshio near the Izu Islands, the appearance of the cold water mass east of Miyake-jima and the relation between the variation of the Kuroshio main current east of Inubo-zaki and existence of this cold water mass. But as we have already noticed data are too scanty to discuss the variations of current. In order to obtain continuous data of the current, it is desirable to install tide gauges in the Izu Islands where we can obtained the relative value of the current velocity by gaining differences of sea level at different tidal stations. That is, if tide gauges could be installed in Nii-jima, Miyake-jima, Hachijo-jima and Aoga-shima, the relative current conditions between two islands could be seen clearly.

Next, we must study the current profile of the Kuroshio and the Oyashio. The author already reported that it is necessary to study the current profile of the Kuroshio near the Izu Islands.

J. Fukuoka: The Variations of the Kuroshio Current in the Sea south and east of Honshu

Moreover, it is important to observe the current profiles of the coastal Oyashio and the off-shore Oyashio in order to determine the origin of the cold water mass east of Miyake-jima. It is interesting to note that the cold water mass occupies over the Japan trench. (Fig. 3) If the cold water mass is due to upwelling, we must study how deep the upwelling appears from. We will look forward to observe at least till 4000 m depth because to assure the upwelling.

Acknowledgement: It is pleasure to express author's thanks to Dr. Nakano, Dr. Yoshida and Dr. Nan'niti for their encouragement and advice.

References

- FUKUOKA, J. 1958: On the Kuroshio near the Izu Islands. Journ. Oceanogr. Soc. Japan Vol. 14, No. 1, pp 11-14
- ICHIYE, T. 1957: On the Behaviour of the Vortex in the Polar Front Region. (Hydrography of the Polar Front Region 1) Oceanogr. Mag. Vol. 7, No. 2, pp 115-132
- ROSSBY, C-G. 1940: Planetary Flow Patterns in the Atmosphere. Quart. Journ. Roy. Meteor. Soc. Vol. 66, Supplement pp 68-87
- UDA, M. 1938: Hydrographical Fluctuation in the North-Eastern Sea Region adjacent to Japan of the North Pacific Ocean. (in Japanese) (A Result of the Simultaneous Oceanographical Investigations in 1934-1937) Journ. Imperial Fisheries Experim. Stat. No. 9, pp 1-66 March

Studies on the Inter-relationship between the Sea and the Atmosphere (Part 4)

By

Masao HANZAWA

Japan Meteorological Agency

Abstract: Through the course of 1955, the sea surface temperatures along the western coasts of both North and South America were anomalously low with strong persistency, while, on the other hand, these of eastern Asia namely along the Pacific side of Japan and the Philippine Islands were rather high. These anomalous oceanic conditions can be explained from the stand point of the drift current theory. Transport of water due to winds over the North Pacific Ocean, covering the area of 25°N—55°N; 130°E—120°W, was calculated with 10° lat.-long. intervals, after Montgomery's manner. Anomalies of this transport from the average conditions show that in 1955 the transport was above normal in the regions of the Gulf of Alaska and the southeastern part of the North Pacific. It is concluded that this above normal transport, due to the prevalence of the so-called Pacific High, brought about the anomalous surface temperatures along both boundaries of the North Pacific.

1. Introduction

In his previous reports (HANZAWA 1956, 1957 and 1958), the author studied the relationship between the sea and the atmosphere, and pointed out the close relationship between the anomalies of sea surface temperatures and the activities of the Pacific High. This was especially demonstrated by the example of 1955. Starting from the consideration of the momentum transfer at the sea surface, C.-G. ROSSBY and R.B. MONTGOMERY (1936) developed a theory of transport of surface water due to the winds. R.B. MONTGOMERY (1936) has shown such transport over the North Atlantic. Using these theories, the author calculated the transport of surface water due to winds over the North Pacific for the year 1955. The average condition of transport was also calculated from the mean meteorological conditions, as were the anomalies of 1955.

The transport was above normal in the region of the Gulf of Alaska and the

south-eastern North Pacific, while in the middle belt, namely along the 35° lat. line, the transport was about normal; as shown by the yearly-mean pattern of 1955. This shows that along the edge of the Pacific High, the transport was above normal due to the prevalent condition of the high. Such conditions are favorable to the transport of cold northern water to the coasts. It can be supposed that the said-transport eventually brings about cold (below normal) temperatures along the western coast of America, and warm (above normal) temperatures along the eastern coast of Asia.

2. *Anomalous ocean surface temperatures in 1955*

1) Coastal temperature

The year of 1955 was characterized by the occurrence of anomalous sea surface temperatures* especially along the coast of North America and Asia. Extremely low temperatures along the western coasts of both North and South America, and considerably higher temperatures along the coasts of Japan and the Philippine Islands (Pacific side) were reported by RODEWALD (1957), and also by RODEN et al (1958), REID Jr. (1958) and HANZAWA (1957 and 1958). In addition, record high sea water temperatures along the east coast of North America in the summer of 1955 were reported by C.B. TAYLOR (1957).

As RODEWALD and TAYLOR reported in detail, the anomalous state is vividly shown in the following table. Along the coast of Japan, the warming of coastal

Table 1 Yearly mean water temperature of 1955. ($^{\circ}$ F) (After RODEWALD 1957)

Name of coast	Deviation from normal
Aleutian to Alaska	— 0.9
Washington to Oregon	— 1.7
California	— 1.2
Mexico, Middle America, Columbia	— 0.4
Pacific Islands	— 0.5
Philippine	+ 0.2
Average deviation — 0.7	

* monthly means

Mean water temperatures for July-August, 1955. (°F) (After TAYLOR 1957)

Station	Month	1955	Av.	Diff.
Boston	July	68.7	64.5	+ 4.2
	Aug.	70.7	65.6	+ 5.1
New York	July	73.1	71.6	+ 1.5
	Aug.	76.5	73.3	+ 3.2
Atlantic City	July	70.2	69.5	+ 0.7
	Aug.	75.1	71.7	+ 3.4
Philadelphia	July	84.1	78.6	+ 5.5
	Aug.	79.7	78.4	+ 1.3
Baltimore	July	82.9	79.6	+ 3.3
	Aug.	81.2	79.6	+ 1.6
Washington	July	85.3	83.6	+ 1.7
	Aug.	80.7	82.1	- 1.4

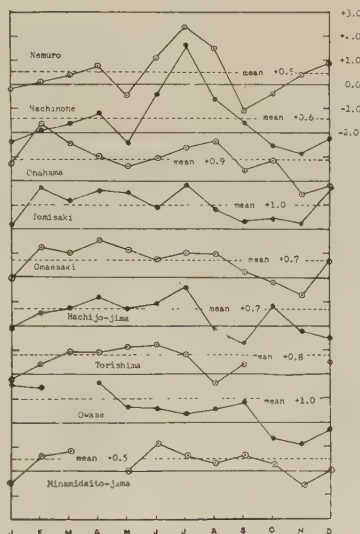
Av. Diff. + 2.5

temperatures were not so remarkable in 1955, yet during that year we could detect a tendency to high sea surface temperatures everywhere along the coast of Japan.

Fig. 1 Anomalies of monthly means of water-temperature at the coastal stations in Japan for the year 1955. (°C)

Locations and series of observation are as follows:—

- Nemuro (43°20'N, 145°35'E; 1929-1957)
- Hachinohe (40°32'N, 141°32'E; 1948-1957)
- Onahama (36°56'N, 140°54'E; 1939-1957)
- Tomisaki (34°55'N, 139°49'E; 1934-1957)
- Omaesaki (34°36'N, 138°13'E; 1934-1957)
- Hachijo-jima Island (33°06'N, 139°47'E; 1936-1957)
- Torishima Island (30°28'N, 140°18'E; 1947-1957)
- Owase (34°04'N, 136°12'E; 1941-1957)
- Minamidaito-jima Island (25°49'N, 131°14'E; 1946-1957)



2) Offshore temperatures

Temperatures of the sea surface of the middle or offshore part of the Pacific in the year of 1955 were not available on a monthly mean basis. Actually, in the

summer of 1955, Operation NORPAC took place under the auspices of U.S.A, Canada and Japan. Surface isotherms covering the whole Pacific are available but since the long year averages are given in the form of means for squares 5° in latitude and 5° in longitude (U.S. Weather Bureau (1938)), it is somewhat difficult to compare the static means with synoptic isotherms. However, the results will be given in a future report.

3. *Transport of water due to winds over the North Pacific*

MONTGOMERY (1936) developed a theory to compute the transport of surface water due to winds from available meteorological observations. Wind observations at sea are sparse and are usually centered on a few special merchant ship courses. It is also difficult to make statics of winds over the ocean. Therefore, use of the mean weather chart is considered.

From the monthly mean atmospheric pressure charts, gradient winds are calculated at 10° -lat., 10° -long. intervals over the North Pacific, 25°N - 55°N , 130°E - 120°W (except for land areas). The angle between surface wind and gradient wind is given by:

$$\frac{U_g}{f z_0} = \frac{2\sqrt{2}k_0}{9k^3} \cdot \csc \varphi_0 \cdot e^{\frac{2k_0}{3k} \left(\cot \varphi_0 - \frac{1}{\sqrt{2}} \right)}$$

from Montgomery-Rossby's theory. Here, U_g is the gradient wind speed, f the Coriolis parameter ($2\Omega \sin L$), z_0 the characteristic roughness of the sea surface, k_0 the constant, ($k_0 = 0.38$), k the constant ($= 0.065$), φ_0 the angle between surface wind and gradient wind. The surface stress given in terms of U_g , φ_0 , and the air density ρ , is:

$$\tau_0 = \frac{9k^2}{4} \rho U_g^2 \sin^2 \varphi_0.$$

Using the relations, $\tau_0 = fT$, the transport of water is given by the formula:

$$T = \frac{9k^2}{4} \frac{\rho}{f} U_g^2 \sin^2 \varphi_0$$

The transport is calculated by use of this formula at the said points. The value of z_0 is, of course, variable but to make computation simple, it is taken as a constant ($z_0 = 0.6\text{cm}$) which is generally accepted.

The value of air density is also variable according to meteorological conditions.

However, the most probable values are taken from the mean climatic conditions (U.S. Weather Bureau (1938)). Monthly mean transport values of 1955 are calculated and are plotted on maps. The yearly mean state chart is given in the following figure.

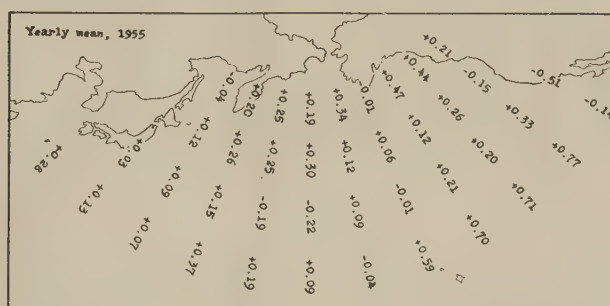


Fig. 2 Yearly mean departure values of the transport of water due to winds over the North Pacific at 10°-lat., 10°-long. intervals for the year 1955. Unit: tons/meter/second.

As for the monthly mean atmospheric pressure charts of 1955, we have used the charts prepared by the Japan Meteorological Agency, and for the mean monthly atmospheric pressure chart, the one published by the U.S. Weather Bureau (1952) was adopted. The magnitude of the transport T is given in tons per second across a vertical surface normal to the net drift and 1 meter wide, using ρ and f in c.g.s. units and Ug in m.p.s.

The actual value of transport is of the order of 0.20~1.33 tons/m/sec which roughly coincides with the value obtained by MONTGOMERY.

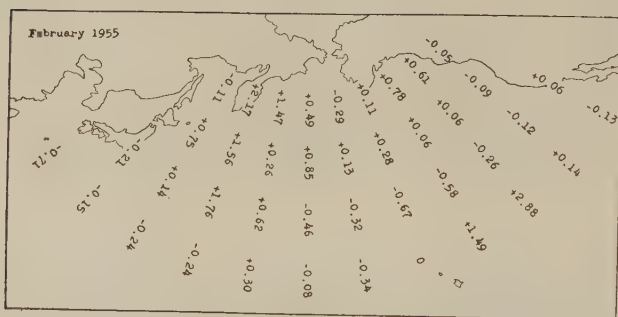
4. Anomalies of transport of surface water in 1955

The difference between the average state of transport and the state for 1955 was calculated for each point. The plotted charts were constructed for the whole year on a monthly basis, and are given in the following figures.

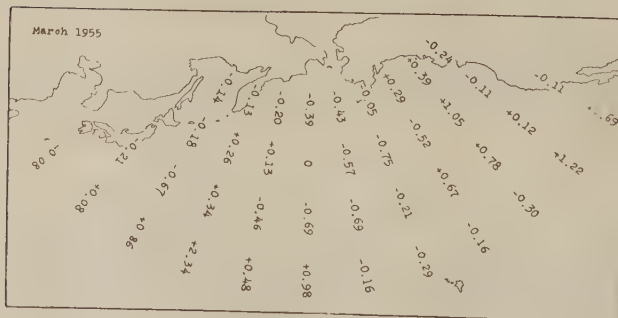
3 - (a)



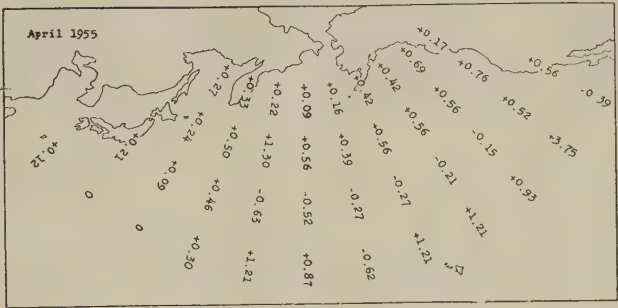
3 - (b)



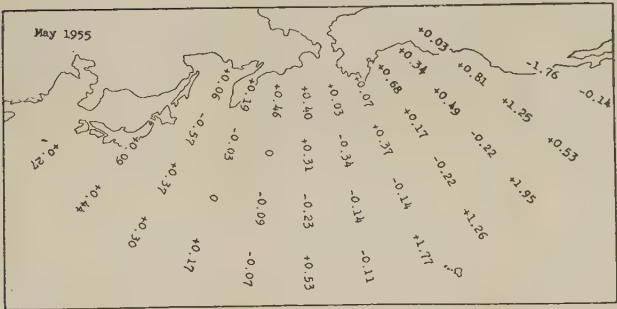
3 - (c)



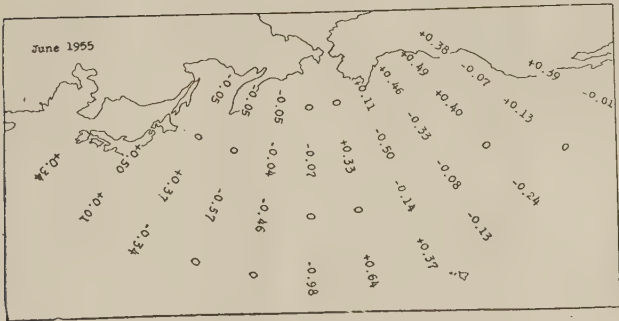
3-(d)



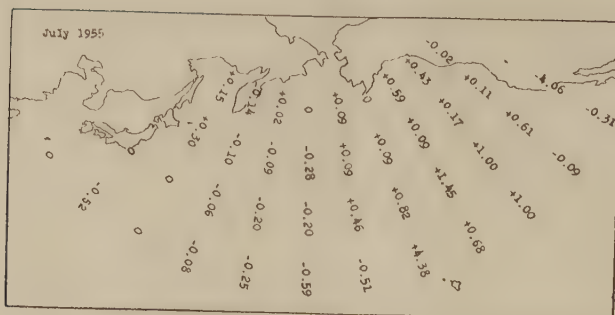
3-(e)



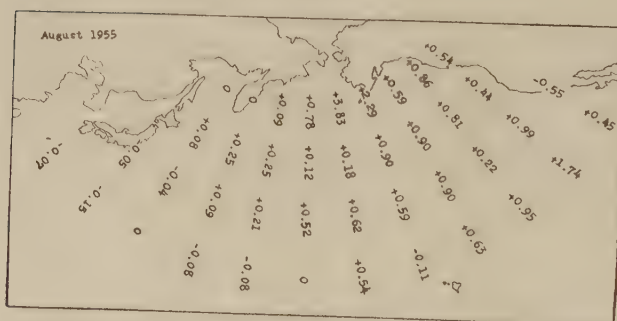
3-(f)



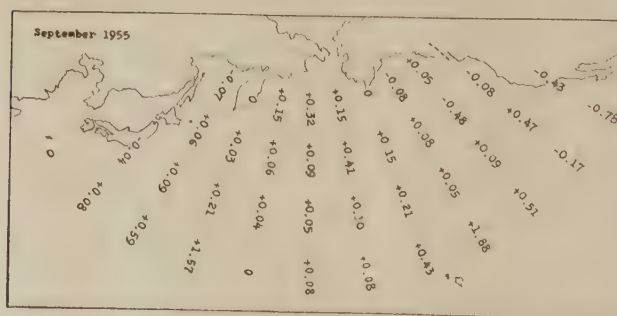
3-(g)



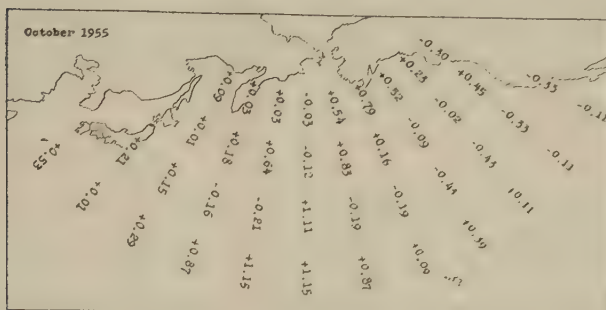
3-(h)



3-(i)



3-(j)



3-(k)



3-(l)

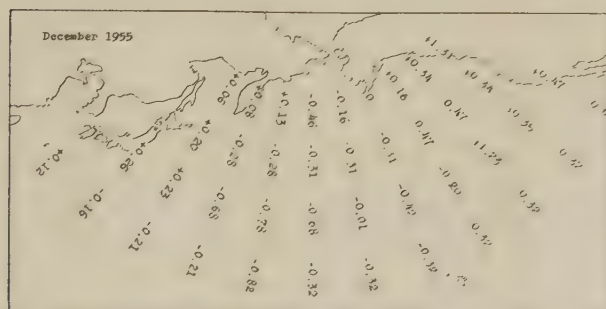


Fig. 3 (a-l) Anomalies of monthly means of water transport from the long year averages for the year 1955, Unit: tons/m /second.

Glancing at these figures, the characteristic points are 1) the strong above normal along 55°N lat., especially in the region of the Gulf of Alaska, 2) the near normal along 35°N lat. belt, especially in the eastern region of the Pacific, and 3) the strong above normal along 25°N between Baja California and the Hawaiian Islands. In the latter case, the anomaly often amounts to $+1.0 \sim +2.0$ tons/m/sec, having a maximum of $+2.88$ tons/m/sec in Feb. 1955.

5. *Consideration*

Since the anomalous sea surface temperatures are seen almost simultaneously along the western coasts of both North and South America, and along the eastern coasts of Japan and the Philippines*. Causes of such phenomena would appear to be related to the global or, at least, semi-global activities of some atmospheric and/or oceanic motive force. The author previously pointed out the prevalence of the Pacific High and the simultaneous weakness of the Aleutian Low throughout the year 1955. C.B. TAYLOR examined the extremely high sea surface temperatures along the east coast of the U.S. in the summer of 1955, and considered a meteorological effect, related to especially high air temperatures and run-off effect. He gave special considerations to hurricanes Connie and Diane and their effect on high sea surface temperatures.

On the other hand, modern developments of physical oceanography indicate that the surface circulation of the ocean are mainly produced by winds. MUNK (1950) and HIDAKA (1950) originated the so-called wind-driven circulation theory. The theory used in this study is, however, a drift-current theory developed by ROSSBY and MONTGOMERY and is different from the so-called wind driven theory.

It is difficult to determine or estimate to what extent amount the actual surface water transport is delineated by such theories. Therefore, transport values as shown in Fig. 3 should be considered as a kind of "indicator" to show, in a relative sense, where the transport is strong and where it is weak. Of course, it is extremely difficult to conclude exactly the causes of the anomalous sea surface temperature of 1955. Strong water circulation as the result of the prevalence of the Pacific High, as pointed out by the author, should be one cause. As far as the summer anomalous sea temperatures along the coast of eastern U.S. is

* Temperatures of the eastern side of the Atlantic, namely those of the coast of Europe and Africa are not available at present.

concerned, the direct meteorological effect, as pointed out by TAYLOR, should be the another cause. Furthermore, though not treated quantitatively here, the effect of upwelling of cold water off California due to abnormal atmospheric circulation in the year of 1955 should be considered.

6. *Summary and conclusion*

1) The anomalous sea surface temperatures observed in 1955 along the west coast of North America and the coasts of Japan and the Philippine Islands were studied.

2) The prevalence of the Pacific High in the year of 1955 was noticed as one of the reasons bringing about the anomalous sea state.

3) Transport of the sea surface water due to wind was calculated for points separated by intervals of 10° lat. and long. in the North Pacific Ocean.

4) Positive anomalies of transport of sea surface water, as compared with normal year, were observed at the edge of the Pacific High, namely in the Gulf of Alaska and in the southeastern Pacific.

5) It is proposed that because of the above normal transport in such regions, the cold northerly water was supplied more abundantly along the coast of the U.S., and conversely, warm southerly water was transported from the south to the coasts of the Philippine Islands and Japan.

6) These conditions were favorable for bringing about warm sea surface temperatures along the coast of Asia and low sea surface temperatures along the western side of North America in the year 1955.

Acknowledgements The author wishes to express his sincere thanks to Dr. Y. TAKENOUTI of the Japan Meteorological Agency and to Dr. K. YOSHIDA of the Tokyo University for valuable advice of this paper. He is also indebted to Drs. G.I. RODEN, M. ROBINSON, J. REID Jr. of the Scripps Institution of Oceanography, La Jolla, U.S.A., and to Dr. M. RODEWALD of the Deutscher Wetterdienst, Seewetteramt, Hamburg, Germany for furnishing him valuable data and documents.

References

Coast and Geodetic Survey (1956): Surface water temperatures at tide stations, Pacific Coast, North and South America and Pacific Ocean Islands. Special Publication No. 280, 5th Ed.

- HANZAWA, M. and T. INOUE (1952): Relation between oceanic and atmospheric state in the North Pacific Ocean for the years of bad and good rice crop. (In Jap.) *Oceanogr. Rep. C.M.O.*, **2** (3), 65-70.
- HANZAWA, M. (1956): Preliminary report on a close relationship between surface water temperatures at the two separated ocean weather stations, Papa and Tango. *Oceanogr. Mag.*, **8** (2), 157-160.
- HANZAWA (1957): Studies on the inter-relationship between the sea and the atmosphere (Part 2). *Oceanogr. Mag.*, **9** (1), 87-93.
- HANZAWA, M. (1958): Studies on the inter-relationship between the sea and the atmosphere (Part 3). *Oceanogr. Mag.*, **10**, 1, 91-96.
- HIDAKA, K. (1955): Wind driven currents and surface contours in an enclosed ocean and the lateral mixing. *Geophys. Notes*, **3**, 12.
- MONTGOMERY, R.B. (1936): Transport of surface water due to the wind system over the North Atlantic. *Pap. phys. Oceanogr. Met.*, **4**, 3.
- MUNK, W.H. (1950): On the wind-driven ocean circulation. *Journ. Met.*, **7**, 2, 79-93.
- REID Jr., G.I. RODEN, and J.G. WYLLIE (1958): Studies of the California Current System. Contributions from the Scripps Institution of Oceanography, New Series No. 998.
- RODEN, G.I. and J.L. REID Jr. (1958): On a relationship between the variations in atmospheric pressure and sea surface temperatures in the North Pacific Ocean. (Unpublished manuscript)
- RODEWALD, M. (1952): Das Meteorologisch merkwürdige Jahr 1925. *Ann. Meteorol.*, Band **5**, Heft 3-5, 122-129.
- RODEWALD, M. (1957 a): Beiträge zur Klimaschwankung in Meere. Die Temperaturen der pazifischen Küstengewässer Nordamerikas von 1920 bis 1955. *D.H.Z.*, Band **10**, Heft **4**, 147-151.
- RODEWALD, M. (1957 b): Beiträge zur Klimaschwankung in Meere. Das kalte pazifische Jahr 1955. *D.H.Z.*, Band **10**, Heft **4**, 151-157.
- ROSSBY, C.-G. and R.B. MONTGOMERY (1935): The layer of frictional influence in wind and ocean currents. *Pap. phys. Oceanogr. Met.*, **3**, 3.
- Scripps Institution of Oceanography (1956): NORPAC Hydrographic Data. SIO Reference 56-4.
- TAYLOR, C.B. (1957): Extreme sea water temperatures and densities along the Northern Atlantic States during summer 1955: *Journ. Mar. Res.*, **16**, 1, 1-7.
- U.S. Weather Bureau (1938): Atlas of climatic charts of the oceans. W.B. No. 1247.
- U.S. Weather Bureau (1952): Normal weather charts for the Northern Hemisphere. Technical Paper No. 21.

Internal Waves in The Open Ocean

Masashi YASUI

Japan Meteorological Agency

1. Introduction

The nature of internal waves has been extensively studied by many authors since the classical works of STOKES and WEBB (Lamb, 1932, p. 370). HELAND-HANSEN (1930) analyzed the data of the "Michael Sars" expedition and concluded that the vertical fluctuation of isotherms might be caused by tidal currents. Later DEFANT (1932) with data of the "Meteor" expedition, LEK (1938) with data of the "Snellius" expedition and SEIWELL (1939) with data of the "Atlantis" expedition demonstrated the existence of internal waves and made important contributions. Recently RUDNICK and COCHRANE (1951) found internal waves with tidal periods on successive BT records obtained at the weather station. Three vessels of the Scripps Institution of Oceanography were assigned to three stations in the sea west of California for the observation of internal waves. The results of this cruise were reported by REID (1957).

Beside intrinsic interest, studies of internal waves are also very important to formulate results of oceanographic observations. DEFANT (1949) concluded that internal waves play a role in the mixing process, and suggested that they might have an effect on upwelling. DEFANT (1950) discussed their effect on dynamical topography and indicated the necessity of correction for their effect.

In the seas adjacent to Japan, the existence of internal waves must be found by analyzing data of ordinary hydrographical cast, though Japanese oceanographers have had no chance to investigate or to make a plan for the direct measurement of this wave.

In June and July, 1957, four research vessels, belonging to the Japan Meteorological Agency and the Hydrographical Office, were operated in the polar front region of the western part of the North Pacific. In this operation, the attention was paid to study the effect of internal waves on the thermal structure of the subsurface layer, which are discussed after the data obtained in a period of not so short as to consider simultaneous observations. The original plan was to make successive measurements of vertical distribution of water temperature during

a period of longer than one pendulum day at two stations, one in the Kuroshio region and the another in the Oyashio region. However M. R. S. Ryofū Maru, assigned to a station in the Kuroshio area, was obliged to leave its position owing to an urgent disease of one of crew.

The author wishes to analyze and discuss the results of continuous observations taken in the upper 250 m layer of the Oyashio area.

2. The station and methods.

For purposes of this investigation, it was desirable to select a station where the horizontal gradient of water temperature would be as small as possible for a considerable distance in all directions. In practice, it was very difficult to find point exhibiting such a condition in this area because of the polar front. Finally the station was located at a position about 100 miles east of Kinkazan (mean position: $38^{\circ} 08.8' N$, $143^{\circ} 58.5' E$) in a region where the horizontal gradient of water temperature was a little small. However the Kuroshio Main Axis was in a short distance to the south of this station. But it was expected that the movement of the water mass in the N-S direction would be very slow. This point was fortunately, very close to the area where current measurement were being made with parachute drogue (Fig. 1).

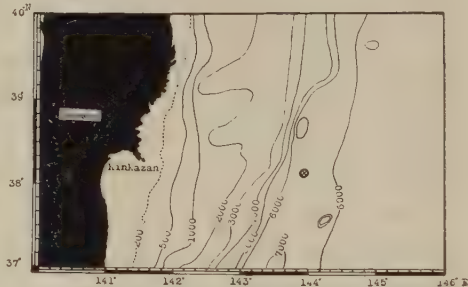


Fig. 1. Bathymetric chart (in meters) and location of the station

The total period of actual operation at this station extended from 14 00 on June 29 to 04 00 on July 1, 1957 (GMT). During this period M. R. S. Shumpu Maru, assigned to this station, was not anchored and occasionally it was necessary to sail back to the position. Checks on the position of the ship were maintained by successive Loran observations and the ship was held within circle with a radius of 5 miles. The position of the "Shumpu Maru" during this operation is summarized in Fig. 2.

Thermal vertical distributions were obtained with a bathythermograph every 30 minutes, and at the beginning and end of observations, waters at standard depths were sampled with Nansen-type water-bottles attached with a depth-meter.

Bathythermograph observations were started at each standard time and were finished within 3 minutes more or less. Therefore, it seems to be unnecessary to

correct on the time at which the temperature in the lower layer was observed. We may adopt the beginning time as the time of observation for all layers. All

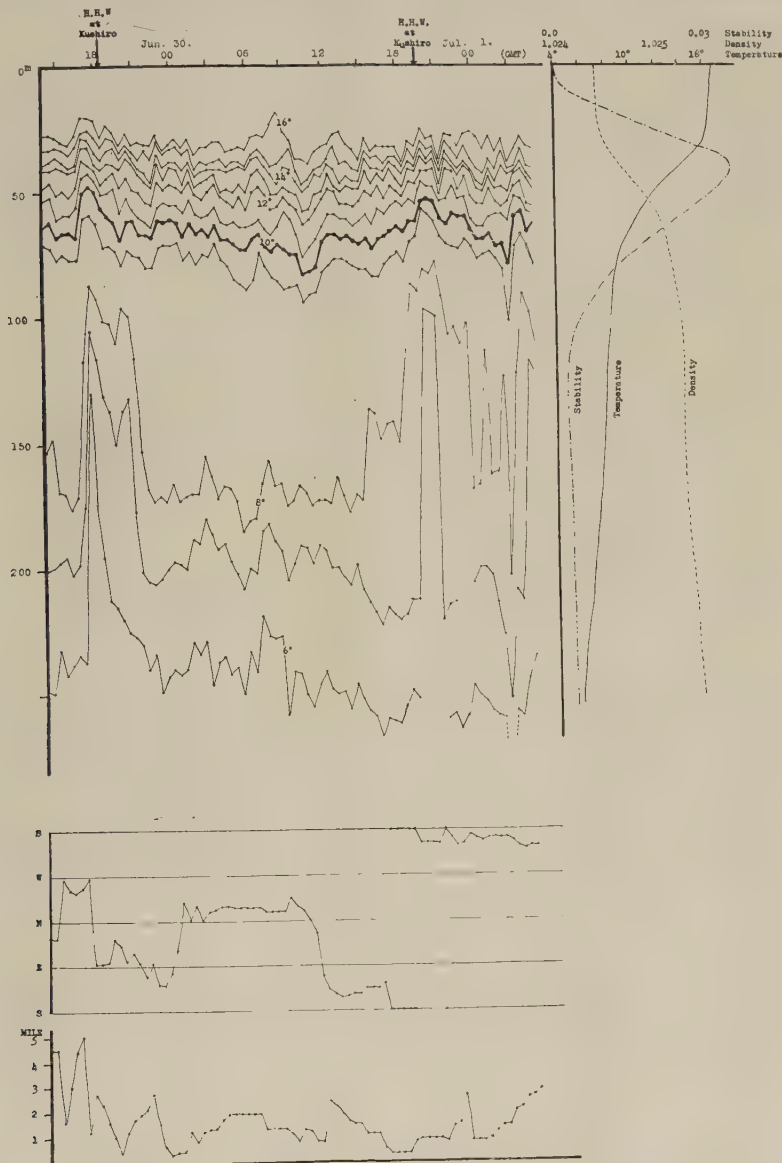


Fig. 3. Fluctuations on the depth of isotherms (left), and mean vertical distributions of temperature, density and stability (right).

Fig. 2. Position of Shumpu-Marui in polar co-ordinate, for the mean position.

records taken by the bathythermograph were printed on photographic paper with the standard grid and the temperatures were read for the cards.

3. *Summary of the vertical displacement of isotherms.*

The variation in depth of isotherms, plotted against time, is summarized in Fig. 3 (left). Although we immediately obtain the impression that some vertical oscillation took place from this diagram, its contours are too complicated to accurately discern its periods by inspection. Roughly, the interval between times at which a isotherm comes up to the shallowest layer might be a period of 24 to 26 hours, but we cannot get more precise information from this figure.

The phases of oscillation appear to vary slightly with depth. If there was nodes of internal waves in the upper 250 m layer, this layer should theoretically be divisible into two layers, the wave motion in one being the complement of the wave motion in the other. From the observations, we were unable to make this division. On the other hand, during the total observational period the times at which all isotherms reached the shallowest vertical position coincided well with the predicted time of the higher high water at *Kushiro* at the same longitude as the station. Indications are that this oscillation is of a higher order, probably the second order, as FJELDSTAD'S (1933) theory and the mean vertical density distribution in this area of the sea suggest.

In Fig. 3 (left), amplitudes of fluctuation at depths over 100 m are far larger than those in the upper 100 m layer, but its movement is more impulsive than periodic. Assuming that the wave of second order is dominated in this upper layer as the author mentioned above, the wave must have the maximum amplitude in the layer below first thermocline. And in the view-point of accuracy in reading of BT records, depth of isotherms in thermocline must be more precise than in lower layer.

Mean vertical distribution of temperature is shown in Fig. 3 (right) and, the distribution of density and vertical stability is also shown in the same figure for the sake of reference. On this figure, the temperature at the central depth of the thermocline is about 12°C.

4. *Analysis of time variation in depth of isotherms.*

According to the above argument, we should numerically analyze the variations in the depth of 10°C isotherm. But, because of complication of the curve, it is very difficult to find the period of oscillation. It is probable that this complicated

variation may be the combined result of many waves with different amplitudes and different periods. Therefore, differentiating and integrating this complicated variation with time numerically we can get two curves. In one, the oscillations with shorter period dominate and in the other these with longer periods dominate as NAKATA (1943) mentioned.

To find the shorter periods involved in the fluctuation, we can compute the auto-correlation ratio of this differentiated curve and draw the periodgram (Fig. 4). On this diagram, the ratio values for periods of 2 1/4 and 4 hours are somewhat dominant but the correlation ratio is so small (about 0.3) that we cannot

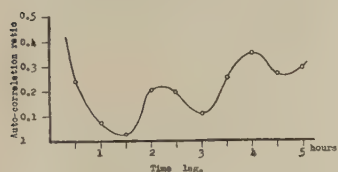


Fig. 4. Periodgram for the fluctuation on the depth of 10°C isotherm.

recognize any reasonable period in this short range. Probably this irregular oscillation of very short period is far shorter than the intervals used in this observation. If so, this would eliminate this short period variation from our discussion. But if we want this short period oscillation to be filtered out, it is desirable to take a running average of 4 hours.

On the integrated curve, the periods are too long to allow us to compute auto-correlation. The undulation of the curve are too minor for us to compute the crests from the observations available.

Helland-Hansen, Seiwel, Defant and other oceanographers have mentioned that internal waves had the tidal period and DEFANT (1940) has shown that the period of free oscillation of the boundary surface in the open ocean coincides approximately with the period of the inertia oscillation. In this point, the period of the inertia oscillation, *viz* the half pendulum day, is about 20 hours and is comparatively close to the period of the diurnal tide. The curve resulting from these two oscillations becomes so indistinct that the time interval between the crests can be computed at any period between 18 and 26 hours.

To study these curves, we try to fit a harmonic series that will satisfy the three components, that is, the Luni-solar diurnal period (23.93 hours), the principal Semi Dirunal period (12.42 hours), and the period of the half pendulum day (19.8 hours), using the least square method.

The results of this computation performed for depths of the 10°C isotherm are tabulated in Table 1 and the resultant curve is shown in Fig. 5. On this table and figure, it is very impressive that the amplitudes of the components are somewhat greater than those of noises. But, phases of tidal components seem

Table 1. Results of harmonic analysis of fluctuation
of the depth of 10°C isotherm.

Period	Amplitude in meter	Phase in radian	Difference between the time for maximum or minimum value and meridian passage of the moon in hours.
Luni-solar diurnal	10.4	+ 3.08	0.0
Semidiurnal	2.2	+ 3.17	1.2
Inertia period	6.0	- 0.50	—

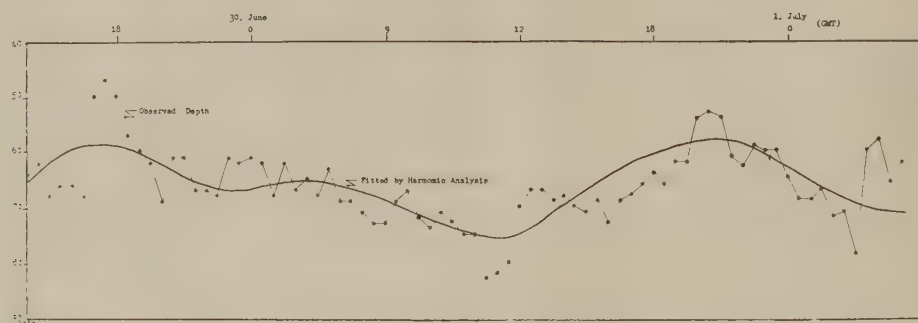


Fig. 5. Resultant curve fitted by Harmonic Series with three periods.

very reasonable because the times at which values of components reach their minimum are closely connected with the meridian passage of the moon.

5. Discussion.

These fluctuation on depths of isotherms can, of course, be caused by horizontal displacement of water mass, but after MASUZAWA (1958), changes of oceanographical conditions in this period are very slight and if it is assumed that fluctuations are caused by the horizontal tidal current only, the mean velocity of the tidal current must be at least 50 cm/sec in the 100 m depth according to the horizontal temperature gradient in this period. But, after TAKENOUCHI (1958) we can not recognize any tidal current in this area from the measurement of sub-surface currents with the parachute drogue.

Then sudden upward and downward movement in depths of isotherms below 100 m which is occurred before or after the time of the high water may be caused by horizontal movement of water particles on orbits of internal waves. While, many small thermal inversion layers were shown on BT records only in this period

which were never appeared throughout the period of this observations except on the time of the high water (Fig. 6).

On the other hand, fluctuations may be affected by change of the atmospheric pressure, but from our observations we can not recognize any correlation between the depths of isotherms and the atmospheric pressure.

HAURWITZ (1954) tested statistically several data on the basis of which the existence of internal waves had been deduced and showed that the observation in such short period as 2 or 3 days contributed in no large measure to occurrence of internal waves. Of course, the period of our observation was too short to apply this statistical test, but on basis of the above discussion the author concludes that fluctuation in depths of isotherms must be caused by internal waves.

Acknowledgment. The author wishes to express his hearty thanks to Dr. Y. TAKENOUCHI, Dr. J. MASUZAWA, Dr. K. YOSHIDA, Dr. C.S. COX and Mr. M. HANZAWA for their valuable suggestion and also to Mr. T. TSUCHIDA and Miss M. USHIO for their assistance.

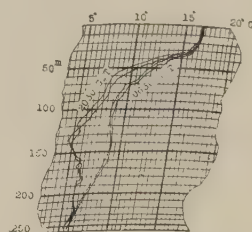


Fig. 6. Typical BT diagrams on the high water (06^h 30^m GMT) and the low water (20^h 30^m GMT).

References

- DEFANT, A., 1932; Die Gezeiten und inneren Gezeitenwellen des Atlantischen Ozeans. Deutsche Atlantische Exped. *Meteor* 1925—1927, Wiss. Erg., Bd. 7, Heft 1, 1932.
- 1940; Die Ozeanographischen Verhältnisse während der Ankerstation des *Altair* am Nordrand des Hauptstromstriches des Golfstroms nördlich der Azoren. Ann. d. Hydrogr. u. Mar. Meteor., November-Beiheft, 4, 1940.
- 1949; Über interne Gezeitenwellen und ihre Stabilitätsbedingungen. Archiv für Meteor., Geophysik. und Bioklimatologie, Serie A, Band 7, 1954.
- 1950; Reality and illusion in oceanographic surveys. Jour. of Mar. Res. **9** (2), 1950
- FJELDSTAD, J.E., 1933; Interne Wellen. Geofysiske Publikasjoner, Oslo. **10** (6), 1933.
- HAURWITZ, B. J., 1954; The occurrence of internal tides in the ocean. Archiv für Meteor., Geophysik. und Bioklimatologie, Serie A, Band 7, 1954.
- HELAND-HANSEN, B. 1930; Physical oceanography and meteorology. *Michael Sars North Atlantic Deep-Sea Exped.*, 1910, Rept. Sci. Results, vol. 1, 1930.

- LEK, L., 1938; Die Ergebnisse der Strom-und Serienmessungen. *Snellius* Exped. in the eastern part of the Netherlands East-Indies, 1929—1930, **2** (3),
- MASUZAWA, J., 1958; A short-period fluctuation of the Kuroshio east of Cape Kinkazan. *Oceanog. Magaz.* **10** (1), 1958.
- NAKATA, Y., 1943. Studies on the periodic variation of the air temperature (in Japanese). *Memoia of the Central Meteorological Observatory* **24**, 1943.
- SEIWELL, H.R., 1939; The effect of short period variations of temperature and salinity on calculations in dynamic topography. *Pap. Phys. Oceanogr. Meteor.*, **7**(3), 1939.
- RUDNICK, P. and J.D. Cochrane, 1951; Diurnal fluctuations in bathythermograms. *Jour. of Mar. Res.* **10** (3), 1951.
- REID, J., Jr., 1956; Observations of Internal Tides in October 1950, *Trans. Amer. Geophys. Union*, **37** (3), 1956
- TAKENOUCHI, Y., 1958; Measurements of subsurface current in the cold-belt along the northern boundary of Kuroshio. *Oceanogr. Mogaz.* **10** (1), 1958.

気 象 庁

欧 文 海 洋 報 告

第 10 卷

THE
OCEANOGRAPHICAL MAGAZINE

Vol. 10



Published by the Japan Meteorological Agency

1958

CONTENTS

J. Masuzawa: A short-period fluctuation of the Kuroshio east of Cape Kin- kazan	1
T. Kawamoto: The construction of parachute drogue	9
Y. Takenouti: Measurements of subsurface current in the cold-belt along the northern boundary of Kuroshio.....	13
T. Ichiye: The response of a stratified, bounded ocean to variable wind stresses	19
M. Miyazaki: A method for the harmonic analysis of tides	65
S. Moriyasu: On the fluctuation of the Kuroshio south of Honshu.....	81
M. Hanzawa: Studies on the inter-relationship between the sea and the at- mosphere (part 3).....	91
T. Ichiye: On convective circulation and density distribution in a zonally uniform ocean	97
A. Okubo: The distribution of dissolved oxygen in the north-western part of the North Pacific Ocean in the aspect of physical oceanography. Part 1. General features of the oxygen distribution (1).....	137
S. Unoki: Wave climate at the Ocean Weather Stations <i>Tango</i> and <i>Extra</i> ...	157
J. Sugiura: On the sea conditions to the east off the Kurile Islands.....	169
R. Marumo, M. Kitou and M. Ohwada: Vertical distribution of plankton at 40°N, 150°E in the Oyashio water	179
T. Nan'niti: Relation between the velocity and the location of the front of the Kuroshio off the Tohoku district	185
M. Kitou: Distribution of plankton copepods at the Ocean Weather Station "X", May 1950 to April 1951	193
J. Fukuoka: The variations of the Kuroshio current in the sea south and east of Honshu (Japan main island)	201
M. Hanzawa: Studies on the inter-relationship between the sea and the at- mosphere (part 4).....	215
M. Yasui: Internal waves in the open ocean	227

昭和34年3月5日印刷

昭和34年3月10日発行

編集兼 気 象 庁
発行人

東京都千代田区大手町一ノ七

印刷人 花 崎 実

東京都中央区新富町二ノ十九

印刷所 大東印刷工芸株式会社

東京都中央区新富町二ノ十九

